UNIVERSITY of TASMANIA

School of Land and Food

Systems for successful innovation: The case of food safety in the Australian red meat industry

by

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Declarations

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The research associated with this thesis abides by the international and Australian codes on human experimentation and the rulings of the Tasmania Social Sciences Human Research Ethics Committee.

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July, 2016

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Abstract

Innovation is considered to be necessary for economic development and global competitiveness. An approach to understanding the innovation process, known as Systems of Innovation, or Innovation Systems, has developed since the 1980s in an attempt to understand, explain and encourage innovation at national, regional, sectoral and technological levels. These approaches have been used to develop policy, but less effort has been made to apply these approaches to the work of the researcher, technologist and practitioner who conduct research and apply the results in the hope that innovation will result. The sectoral and technological systems approaches were selected to analyse the innovation performance of food safety projects in the Australian red meat industry.

This study aimed to determine the value of applying sectoral and technological system failure frameworks at the level of individual projects. The frameworks were constructed as theories, so that they could be tested. The primary research question was whether the theories were able to explain the ability of research to lead to innovation. This study further considered the performance of the innovation system as a whole and the role of the actors in the innovation system.

This study utilised a multiple case study design, collecting data through surveys of people involved in past research and development projects. The principal method of data analysis was fuzzy-set Qualitative Comparative Analysis (QCA), which is suited to the analysis of case study data.

Both the sectoral and technological system frameworks were able to explain the success or failure of projects to lead to an innovation outcome. Projects that did not lead to an innovation outcome had weak elements in both system frameworks. No obvious correlation between the elements of one framework and the other were noted. Analysis of multiple cases of poor innovation system performance revealed that the same elements from each framework were recurrently weak. A detailed analysis of the interactions between actors in this system established the central role played by the intermediary, the research and development corporation charged with managing the projects.

The findings have implications for theory, method, policy and practice. This study has provided evidence that both system failure frameworks include factors significant to predicting innovation failure at the project level. Furthermore, these innovation system frameworks describe a system that operates in a consistent way from project to project. The importance of intermediary functions to innovation system performance is demonstrated. At a methodological level, the work has demonstrated the use of QCA methods for the construction and testing of theory. Consideration has been given to how QCA can be applied to the validation of a measurement system for case study analysis. At the policy level, it is suggested that innovation system failure frameworks could be applied to the design of innovation projects to increase the chance of a successful outcome. The consolidation of the two failure frameworks into one may benefit the

design and management of projects at the intersection of sectoral and technological innovation systems. At the level of practice, this study suggests that innovation system frameworks may provide managers with important insights and guidance for managing innovation projects and that fulfilling the functions of an intermediary may increase the likelihood of an innovation outcome.

Statement of Co-authorship

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Abbreviations

ACCEPT	acceptance, an element in the functional theory
ACTOR	actor competence, an element in the structural theory
DIRECT, D	direction of the search, an element in the functional theory
ENTRE	entrepreneurial experimentation, an element in the functional theory
fsQCA	fuzzy-set Qualitative Comparative Analysis
INNOV	the innovation outcome in fsQCA
INFRA	infrastructure, an element in the structural theory
INSEAD	Institut Européen d'Administration des Affaires
INST	institution, an element in the structural theory
INTER, I	interactions, an element in the structural theory
IS	innovation system
ISP	innovation system performance
KNDEV, K	knowledge development, an element in the functional theory
KNDISS	knowledge dissemination, an element in the functional theory
MARKET, M	markets, an element in the structural theory
MKTFOR	market formation, an element in the functional theory
MLA	Meat & Livestock Australia
OECD	Organisation for Economic Co-operation and Development
QCA	Qualitative Comparative Analysis
R&D	research and development
RDC	Rural Development Corporation
RESOURCE	resources, an element in the functional theory
SI	system(s) of innovation
SIS	Sectoral Innovation System
TIS	Technological Innovation System
WIPO	World Intellectual Property Organization
WTO	World Trade Organisation
~	logical operator, NOT

1

Introduction

1.1 Introduction

Since the writings of Joseph Schumpeter (Elliott 1983; Fagerberg 2005) innovation has had a place in the understanding of economic growth and development. Stiglitz, a Nobel Economics Prize-winner and Greenwald, a professor at Columbia Business School, have stated the importance of innovation as follows:

> If our contention that the success of modern economies is due to innovation and learning is correct, then understanding the processes of learning and innovation, and how policy can affect its pace, should be at the center of economic analysis (Stiglitz & Greenwald 2014, p. 16).

Fagerberg (2005, p. 4) makes a distinction between invention and innovation; "Invention is the first occurrence of an idea for a new product or process, while innovation is the first attempt to carry it out into practice." Research is frequently the step prior to invention. Scientific and technical research activities result in discoveries, new perspectives, and factual outputs. The scientific literature exists for the purpose of recording such, usually incremental, advances in science. These scientific outputs may lead to an invention; the first occurrence of an idea for a new product or process. The inventors may perceive an opportunity based on the scientific research, or may be attempting to solve a problem. The importance of invention is exemplified in the patent system, wherein a patent is only issued if the claimed invention passes the test of having an inventive step, exceeding a threshold of non-obviousness. Inventions may patented and licensed, or be in the public domain, leading to changes in practice which diffuse through a community. Innovation does not occur until there is an attempt to put the invention into practice.

Innovation is constantly pursued through government policies (Australia. Productivity Commission 2007), and is seen as a key to economic growth (Verspagen 2007). It is now promoted as a legitimate academic field of study (Fagerberg & Verspagen 2009). However, policy goals can only be realised if the funds expended in research effectively lead to innovation.

In the seminal work on innovation, Schumpeter (1934), recognised five types of innovation:

- New products and product qualities
- New production methods
- New sources of supply
- Exploitation of new markets
- New ways to organise business.

The process from science and technology to an invention then to innovation across a wide range of innovation types is not a solitary occupation for scientists and technologists. A number of people and organisations with varying skills and capabilities are usually involved in the innovation process. Innovation may be affected by a number of factors, including a recognized need for the invention, and circumstances that lead to implementation (Fagerberg 2005).

International organisations (Organisation for Economic Co-operation and Development 2010) and national governments (Australia. Productivity Commission 2007) have desired to encourage innovation and have focused on economic frameworks and overcoming market failures hindering innovation.

More recently, the market failure approach has been supplemented (Bergek et al. 2008; Dodgson et al. 2011) by concerns of innovation failure itself, ensuring that the innovation system is complete and that policies and laws are in place to allow the system to function most effectively (Anonymous 2009; Cutler, Cutler & Company & Australia. Department of Innovation Industry Science and Research 2008; Organisation for Economic Co-operation and Development 2010).

This chapter aims to describe broad government policy for agricultural innovation in Australia and how innovation policy translates to food safety research and development in the Australian red meat sector. Approaches to innovation systems and the understanding of the role of intermediaries in those systems will be briefly described. The questions being raised in this research will then be defined, and a brief outline given of the contributions made by the work described here. Lastly, the structure of this thesis will be outlined.

1.2 Contextual environment

The case studies in this research are concerned with food safety innovation in the Australian red meat industry. It is therefore relevant to consider the context in which these studies were conducted, namely, those Australian Government policies on innovation and rural research and development, the business of the Australian red meat industry, and, finally, the nature of food safety and food safety innovation.

1.2.1 Australian Government innovation policy

Australian Government innovation policy is largely consistent with international trends and national systems of innovation approaches (see following section for a discussion of national innovation systems). Dodgson et al. (2011) reviewed the development of innovation policy in Australia and pointed out a shift, in common with many other countries, from an analysis based completely on idea of market failure to one also considering failures in the innovation system. They also point out that policy decisions are often still driven by market failure arguments rather than innovation systems analysis.

In Australia, the Productivity Commission (2007) enquired into public support for science and innovation, the benefits that arise and how government policy, through institutional and regulatory frameworks, could enhance the benefits that arise. The report found that the public support for science and innovation had provided sizeable net benefits for Australia. The report identified two significant reasons for public funding: that government required innovation to deliver its programs (health, defence, environment etc.) and also because ‘spillovers’ from the innovation could have a benefit beyond those captured by the innovator. The report acknowledged the impact of science and innovation funding on national values and therefore, that providing some support for high risk investment in innovation was justified. Government roles in the innovation system was recommended to be limited to the provision of institutional services (for example, intellectual property protection), support for education and training and in funding high value research that would not otherwise be undertaken by business.

During the period of Labor government (2007-2013) policy was determined by the Cutler review entitled *Venturous Australia: building strength to innovate* (2008) and the Government response *Powering ideas* (Anonymous 2009). The Cutler review moved beyond the concerns of the Productivity Commission (2007) to a review of the innovation system and consequently defined the concerns of government much more broadly:

> Innovation is about far more than the funding of research and science, or even of that and commercialisation. Australia thrives only if a critical mass of business enterprises and workplaces are consistently innovating – not just with next generation products, inventions and technologies, but in their operations, organisation, relationships and business models (Cutler, Cutler & Company & Australia. Department of Innovation Industry Science and Research 2008, p. x).

The report looked at all aspects of a national innovation system and the role of government in ensuring that the system was robust and effective, while acknowledging the key role of the entrepreneur in causing new knowledge and ideas to be applied in a real world context and the diffusion, adoption and adaptation of that innovation.

The Government response to this, and other reviews (Anonymous 2009) produced a commitment to developing and improving the national innovation system. The national innovation priorities set by the Australian Government did not seek to choose technological areas for development but rather "address the country's long-term weakness in business innovation, and in collaboration between researchers and industry" (Anonymous 2009, p. 4).

During the Liberal / National government (2013- time of writing) the innovation agenda was incorporated into a broad competitiveness agenda to provide "a framework for boosting Australian industries' competitiveness and driving greater innovation and investment across the nation" (Australia. Department of Prime Minister and Cabinet 2014, p. 23).

1.2.2 Rural research in Australia

Australian Government support and funding of rural research and development has held a significant position in Government rural policy for a long time. The current incarnation of rural research and development organisations was enabled by the Primary Industries and Energy Research and Development Act 1989 (Council of Rural Research and Development Corporations 2010; Productivity Commission 2011). The objectives of this and analogous previous Acts were to provide a mechanism for socialised industry research in a co-investment model, with funds coming from statutory levies and matching funds from the Australian Government. The research and development corporations (RDCs) created for various rural sectors were expected to develop research and development (R&D) programs to reflect industry R&D priorities, and facilitate the dissemination, adoption and commercialisation of research results. The research was to aim to increase economic, environmental and social benefits for Australia, achieve the sustainable use and management of natural resources and make more effective use of human resources and skills (Core & Australian Department of Agriculture Fisheries and Forestry 2009).

The Cutler review identified an:

> opportunity to: continue to drive agricultural productivity and yields through research; develop globally significant leadership around the development of nutriceutical [sic.] foods; establish a global brand reputation for food safety and certification; and become an Asia-Pacific-oriented location for significant global facilities for biological testing and certification…. The Review consultation process revealed a need for greater national strategic leadership in rural innovation (Cutler, Cutler & Company & Australia. Department of Innovation Industry Science and Research 2008, p. 144).

The Productivity Commission review into rural R&D (2011) reported that a large majority of the participants in the inquiry supported retention of the RDC model and acknowledged that the model is highly regarded internationally. The Productivity Commission recommended that the Government contribution to rural R&D be halved, a view rejected by the Government, which reasserted its support:

> R&D is vital to the ongoing productivity and competitiveness of Australia's rural industries, and in turn the health and resilience of Australia's rural and regional communities. Rural R&D that

> contributes to increased productivity through more sustainable use of natural resources results in significant private and public benefits (Australian Government 2011, p. np).

An Agricultural Competitiveness White Paper (2015) noted that:

> RD&E [research, development and extension] is also helping producers innovate throughout the supply chain. Examples include electronic livestock identification, researching consumer preferences in the domestic market, market and product testing overseas, improving the shelf-life for exported products, or developing innovative new packaging materials to improve food safety and reduce costs or waste. The ability of Australian agriculture to innovate and form successful research collaborations will continue to support a stronger Australian economy with sustainable food security (Australia. Department of Prime Minister and Cabinet 2015, p. 96).

1.2.3 Red meat industry

The Australian red meat industry (cattle, sheep and goats) has an annual turnover of over $20 billion and one of the world's largest exporters of meat and live animals. The industry directly employs approximately 200,000 people. Australia is a major international exporter of both beef and sheep meat; of the red meat produced, over 70% is exported to markets such as Japan, US, Middle East, China and Korea. The industry has an international reputation for food safety, animal welfare and disease control (Red Meat Advisory Council 2015).

Meat & Livestock Australia (MLA) has been an industry-owned corporation, in the RDC model, since 1998 (Productivity Commission 2011). MLA has over 50,000 livestock producer members who are the primary stakeholders in the company (Meat & Livestock Australia 2016). MLA has the role of funding relevant R&D activities, developing and sharing knowledge and delivering value to the industry through implementation of knowledge-based innovations necessarily working with multiple stakeholders. MLA's corporate plan (Meat & Livestock Australia 2012) is aligned to the *Meat Industry Strategic Plan 2010-2015* and Government research and development priorities. The red meat producer 'peak industry councils' – the Australian Lot Feeders' Association, Cattle Council of Australia, Goat Industry Council of Australia and Sheepmeat Council of Australia – set the policy direction through the *Meat Industry Strategic Plan*. MLA also collaborates with other RDCs, particularly the Australian Meat Processor Corporation, which is the RDC particularly charged with meat processing research and development activities (Australian Meat Processor Corporation 2016) and works in partnership with both MLA and the Australian Meat Industry Council, the meat processors' peak industry council (Australian Meat Industry Council 2016). MLA spends approximately $90m each year on R&D.

1.2.4 Food safety and food safety research

Food safety is a subject not readily defined, understood, nor assessed. However, it is subject to national and international laws, rules and agreements, and it is in this context that food safety innovation occurs.

Food safety is a non-obvious property of food; it is defined as an assurance that consumption of such will not cause (relatively) immediate harm to the consumer, or alternatively, that the food does not pose an unacceptable level of risk associated with pathogenic microorganisms, chemical or physical hazards (Desmarchelier & Szabo 2008; Martinez, Verbruggen & Fearne 2013). Food safety is relative concept; there is always a chance that a serving of food will cause an adverse reaction, or illness.

The relative nature of food safety risk is reflected in regular media reports of the incidence of foodborne disease from well-known pathogens as well as from emerging hazards. Attribution of disease is made to foods that have a long historic record of association with illness, as well as to unexpected carriers of disease, and occasional outbreaks due to foods that would usually be considered safe.

Consumers make increasing demands for food safety (Swanson 2011; Unnevehr 2007). Representatives of consumers, such as customers or businesses purchasing food, may also demand food safety. Governments respond to these demands to protect citizens, by encouraging industry development and by making policies that are expected to gain or retain public confidence in the food production system. Laws and regulations define acceptable practices and systems to achieve compliance with those requirements. For over one hundred years, governments have been sufficiently concerned about the quality and safety of food supplied to citizens to enact broad legislation that has placed responsibilities on food businesses and restrictions on their activities (Swanson 2011).

The incidence of disease and the resultant burden on the public health system is not the only factor that affects a government's decision on the stringency of regulation, but also a number of cultural, historical and political factors (Caswell 2008). International trade agreements acknowledge the rights of countries to implement regulations that will provide an 'acceptable level of protection' for their citizens (Whiting & Buchanan 2008), which is not only an acknowledgement that food safety is not absolute, but also that governments may make their own decision about the relative level of safety that is acceptable within their country.

Responsible participants in the industry must invest heavily in knowledgeable staff, product development, packaging design, storage and distribution infrastructure, quality control, systems, certification and licences before they can commence a business operation. Staying in business requires attention to product safety, and, amongst other things, maintaining a good reputation, and having a favourable status with regulators.

Many scientists are employed in the area of food safety, funded by both government, and industry. However, most research is in the public domain, because the research potentially benefits all stakeholders who take the necessary actions to improve food safety. Scientists and technologists often complain that food safety alone is not a driver for innovation and that industry is unwilling to invest in processes and new plant that will not provide a rapid return on investment (Fryer & Versteeg 2008).

Due to weak market signals, strong institutional arrangements are necessary. Attributes, such as food safety, are not often valued in markets because the attribute is difficult for consumers to measure and poor quality can be difficult to judge, even after consumption (Caswell 1998). It is not easy for the supplier to provide information to consumers that will allow them to value the food safety of the product because of the inherent uncertainty and complexity of determining food safety attributes such as the presence of harmful levels of microorganisms. Market signals are thus generally considered too weak for sufficient action to be taken to improve food safety. Rama and Harvey (2009) contend that market failure is apparent in food safety aspects of the Australian food supply chain. They suggest that gaining a poor reputation for food safety might be necessary before a business would take action to improve its performance. Significant actions to improve food safety have often only occurred as the result of regulator intervention, and strengthening of private quality assurance standards in the face of significant foodborne illness and demonstrably inadequate voluntary food safety management systems (Caswell 1998; Unnevehr 2007). Government control of imported foods (Crutchfield et al. 2001) also responds to food safety incidents and concerns within the country, or in other parts of the world, potentially creating a significant technical barrier to international trade (Roberts & Unnevehr 2005).

Approaches to food law have been influenced very heavily by international agreements, particularly the World Trade Organisation (WTO) agreement on Sanitary and Phytosanitary measures (Szabo, Porter & Sahlin 2008). The Sanitary and Phytosanitary (SPS) Agreement of the WTO allows countries to implement risk management measures sufficient to provide an 'appropriate level of protection' chosen by that country, based on an assessment of risks. Other countries, wishing to export their product, must have measures in place that will also ensure this level of protection to consumers in the importing country. This very simple concept leads to a large scientific and technical infrastructure concerned with the assessment of risk (Szabo, Porter & Sahlin 2008). Risk assessment is the basis for defining the burden of illness in a country, and potentially, the level of protection that can be achieved by the implementation of control measures. There are, of course, multiple ways in which a risk can be reduced, which often leads to regulations being written in terms of outcomes, providing industry with options and challenges on the implementation of sufficient operational control of risks (Desmarchelier & Szabo 2008; Martinez, Verbruggen & Fearne 2013). An exporting country may wish to have their risk management measures accepted as equivalent to those of an importing country, which requires the determination of equivalence through risk assessment to demonstrate achieving an equivalent level of protection (Desmarchelier & Szabo 2008; Fryer & Versteeg 2008).

When thinking of food safety innovation and Australian meat, acceptance by regulators of domestic and international trade, which are dominated by the concept of risk, becomes a major criterion for success.

The innovation typology of Schumpeter (1934) is relevant to food safety innovations. The five types of innovation defined by Schumpeter can also be applied to food safety. The product may be new because the product has been reformulated (Loader & Hobbs 1999). For example, a preservative maybe added to the product, either a completely new ingredient, or one that has been used previously only in other products, or one that has been used but at a lower (ineffective) concentration. A new process may be used to produce an existing product (Fryer & Versteeg 2008). For example, pasteurisation (application of heat) may have been used but at a different combination of time and temperature, or the use of a newer technology such as the application of high pressure, or electromagnetic fields. The food producing businesses may have found a new, safer, source of supply for a significant ingredient (Loader & Hobbs 1999). For example, through changed supply chain relationships and the implementation of private quality assurance standards (Henson & Caswell 1999). The business may choose to sell their product only to certain customers for certain uses, to ensure that it is rendered safe for consumers. It is also possible that the business may have been organised in a different way, such as empowering staff to consistently take actions that result in subtle changes to process that makes food safer (Yiannas 2009).

Knowledge about products, processes, sources of safe supply, and systems of production need to be possessed and implemented effectively by the business, and be demonstrated to the regulatory authority. Knowledge, understanding and changes in practice are clearly essential ingredients to a safe food supply. Food safety innovation is a knowledge-based activity. It is heavily dependent on scientific knowledge, from its creation through to its adoption. Organisational innovation (Lam 2005) of scientific knowledge requires the application of knowledge to particular problems and reduction to practice. The social aspects of knowledge creation, organisation, group dynamics and learning are all relevant to successful innovation.

MLA has responsibility for conducting food safety research and development activities on behalf of the Australian red meat industry and to apply the research to the development and adoption of programs that will ensure that food safety risks are reduced and that the industry operates as efficiently as possible. The stakeholders have defined MLA's role as:

> to implement sound management systems to deliver safe and hygienic food that meets consumer and regulatory requirements. This involves the development of pathogen management programs with an emphasis on risk management as appropriate (SAFEMEAT 2012, p. 7).

Research is not performed by MLA itself, but through research organisations and consultants in Australia, as well as internationally.

1.3 Innovation Systems

The linear model of innovation, in which ideas are developed from laboratory to prototype to final commercialisation, often by a single inventor/entrepreneur, or within the one firm, has long been discarded, though it still provides relevant insights (Balconi, Brusoni & Orsenigo 2010; Fagerberg 2005; Godin 2006). A ‘systems’ approach to innovation has been developed through disciplines such as science policy studies, economic geography and sociology in a quest for a deeper understanding of the dynamics of how innovation processes occur (Fagerberg 2005). Models of innovation systems (IS) or systems of innovation (SI), which admit the complexity of innovation, and seek to understand the necessary environments and interactions for innovation to be successful have proven to be useful tools (Manjón & Merino 2012).

Innovation systems thinking had its genesis in the 1980s as an holistic attempt to "describe, understand, explain - and perhaps influence - processes of innovation" (Edquist 1997, p.2). Innovation systems are a conceptual framework rather than a theory, which seek to maintain conceptual ambiguity in an attempt to encompass all important factors in innovation (Edquist 1997). Key aspects of innovation systems are the emphasis on institutions, the dynamic nature of actors within the system, and the boundaries that nevertheless allow a system to be defined.

Four approaches to innovation systems have been developed: national, regional, sectoral and technological (reviewed in Chapter 2). The sectoral innovation system (SIS) approach, focussing on the innovation of a single industry sector, and the technological innovation system (TIS) approach, focussing on a technology, are the most immediately relevant to innovation that may occur in the red meat sector in the area of food safety. Both of these innovation system approaches would be influenced by being within the national innovation system of Australia.

Scholarship on sectoral and technological innovation systems has led to the development of frameworks for analysis of systems to determine the weaknesses of the systems that lead to failure to innovate (reviewed in Chapter 2). Within the SIS literature, an approach to understanding system failure has been developed (Klein Woolthuis, Lankhuizen & Gilsing 2005), that has been characterised as the structural approach (Wieczorek & Hekkert 2012). Within the TIS literature an approach to understanding system failure has been developed, that has been called the functional approach (Bergek et al. 2008). The literature does not record any evaluations of the structural and functional failure frameworks other than being used for analysis and the qualitative assessments of satisfaction of the analysts with the outcomes. Even in the work of scholars who acknowledge both frameworks, there has been no comparison or evaluation of their suitability, other than comparisons based on existing background knowledge and opinions about their comprehensiveness or suitability.

1.4 Intermediaries

Scholarship on innovation systems points to the requirement for actors in the innovation system to interact, make decisions, gain resources and resolve questions of direction to ensure that research leads to innovation. Actors have also been identified as performing tasks that facilitate the operation of the innovation system, or network, and are termed intermediaries (Howells 2006). Various terms have been used for the actor performing this function and various functions have been ascribed to the role (reviewed in Chapter 2). Within the innovation system defined for study, food safety in the Australian red meat industry, MLA is the organisation with the designated role of facilitating innovation.

Little attention has been given to the significance of the role that intermediaries play in innovation systems.

1.5 This research: needs and questions

Andrew H. van de Ven (2007), a social researcher engaged in innovation studies, encourages researchers to be engaged with stakeholders and contributing to both the scientific discipline (theory) and well as practice. Mason (2002, p. 18), encourages social researchers, who may not see their research as theoretical, to express their research questions as answering an "intellectual puzzle". The questions posed here attempt to follow this advice.

Food safety innovation in the Australian red meat industry is a clear industry objective, the achievement of which is supported by industry levies, government funding, a rural R&D system as well as national innovation policies. While the industry has been successful in making changes that have met with the approval of customers, it is highly unlikely that the system for producing innovation is as effective as it could be. The most tangible activity is a government supported RDC, and scientists conducting research, with the clear expectation from government and industry stakeholders that these activities and the outputs of scientific research, will lead to benefits for industry.

Approaches to understanding how innovation occurs, through the systems of innovation approach, have been developed, leading to interventions to improve the operation of innovation systems. However, these innovation system approaches have not been constructed as a theory and, thus, have not been formally tested. Nor have these approaches been applied at the level of projects seeking to translate research into innovation. This situation leads to the central research questions:

RQ1: Does the structural framework of innovation systems explain the ability of research to lead to innovation?

RQ2: Does the functional framework of innovation systems explain the ability of research to lead to innovation?

RQ3: Does a combination of both the structural and functional frameworks better explain the ability of research to lead to innovation?

All of projects studied in this innovation system are conducted through the Rural Development Corporation that has potential to act as an intermediary and influence the direction of innovation. A secondary research question thus concerns the role of intermediaries in the innovation system:

How significant is the role of the Rural Development Corporation as intermediary in the innovation system?

Answering these research questions will allow practical questions to be answered, such as:

How can public and industry funds be applied most effectively to achieve food safety innovation in the Australian red meat industry?

How can managers of industry projects ensure that food safety innovation is more likely as a result of research?

1.6 Contribution of the research

This research contributes to theory, method and practice through understanding the operation of the red meat food safety innovation system through sectoral and technological innovation system lenses.

First, the innovation system failure frameworks are constructed as theory and tested, using fuzzy-set Qualitative Comparative Analysis (fsQCA)[1]. The diversity of the data are limited, which means that not all elements of each theory can be tested, but in all projects examined, weakness in one element of a theory leads to innovation failure. This finding is fundamental to the others because it validates the claims of the innovation systems scholars about the required elements of sectoral and technological innovation systems and the operation of these theories at the project level. Furthermore, this finding suggests that predictions may be made based on the theories, such as the ability to intervene in a project to correct innovation system weaknesses. Proposals are made to combine the structural and functional analytical methods to fully understand innovation system performance and respond to identified weaknesses in the functional failure framework[2]. This study contributes to theory by illustrating how fsQCA can be used for theory testing and how sectoral and technological frameworks can be combined. This study also contributes to the practices of innovation managers by confirming a list of system elements that must be managed to increase the likelihood of innovation.

Second, the system chosen for analysis, food safety innovation in the Australian red meat industry, operates as a system, with the projects failing to lead to innovation often having similar innovation system weaknesses[3]. The demonstration of recurrent innovation system weaknesses in several projects, suggests that the system itself may be subjected to policy and management intervention. Further analysis suggests that these weakness are the result of a number of factors, all of which may be important[4]. This study contributes to policy by suggesting that intervention in certain aspects of systems could improve the performance of that system for multiple innovation projects.

[1] Jenson, I, Leith, P, Doyle, R, West, J & Miles, MP 2016, 'Testing innovation systems theory using Qualitative Comparative Analysis', *Journal of Business Research*, vol. 69, no. 4, pp. 1283-1287.

[2] Submitted manuscript: Jenson, I, Leith, P, Doyle, R, Miles, MP, 'Sectoral and technological innovation system failure frameworks: application to project-level innovation practice' *Research Policy*

[3] Jenson, I, Doyle, R, Leith, P, West, J & Miles, MP 2016, 'Innovation system problems: causal configurations of innovation failure', *Journal of Business Research*, http://dx.doi.org/10.1016/j.jbusres.2016.04.146.

Third, the QCA method usually involves a simple relationship between the antecedent condition and the outcome. This work explores an approach to validation of a two-layered approach to QCA: a measurement layer in which measurements are used to form the condition, and the familiar relationship between conditions and outcome[4]. This study contributes to method by suggesting more sophisticated ways of using QCA in analyses where there are both measurement and causal relationships.

Last, the significance of actors in innovation system performance is assessed and the importance of the involvement of a large number of innovation system actors for the achievement of an innovation system outcome is demonstrated. Also, the importance of the intermediary role in ensuring innovation system performance is described[5]. The effective involvement of the intermediary and inclusion of a network of other actors is of practical significance to innovation management. This study contributes to theory by suggesting the significance of intermediaries in innovation systems.

1.7 Thesis structure

This thesis consists of a central core of chapters that have been published or submitted for publication, and chapters supporting them.

This first introductory chapter provides an orientation to the environment in which the research has been conducted, the opportunities and definition of the research questions.

The literature review (Chapter 2) provides sufficient background on innovation systems and intermediaries orient the reader and to supplement the short reviews of the literature found in the chapters reproducing published research articles.

The method chapter (Chapter 3) provides a detailed justification and exposition of the main methods employed (case study, survey and qualitative comparative analysis), to supplement the necessarily brief methods sections found in the research papers. Additional methods are described in the individual research articles (chapters 4-7.)

The following chapters (Chapters 4-7) reproduce the text of the research papers both published or in press and under review, and present the major research findings and brief discussion.

Chapter 8 presents a detailed review of the sectoral and technological innovation systems literature and the structural and functional failure frameworks arising from those innovation systems and proposes that a combination of these failure frameworks is applicable to the

[4] Jenson, I, Leith, P, Doyle, R, West, J & Miles, MP 2016, 'The root cause of innovation system problems: formative measures and causal configurations', *Journal of Business Research*, http://dx.doi.org/10.1016/j.jbusres.2016.04.127.

[5] Submitted manuscript: Jenson, I, Doyle, R, & Miles, MP 'The significance of actors in innovation system performance' Technovation

analysis of innovation failure at a project level, and is a response to identified weaknesses in the functional failure framework.

In the last chapter (Chapter 9) the results are synthesised to support the claim to contributing to theory, method and practice and the research questions are answered. The limitations of the research and the opportunities for further research are also discussed.

2

Literature review

2.1 Introduction

The research questions in this thesis are concerned with innovation systems and intermediaries, so this chapter provides an overview of this literature. Further narrower focused reviews are provided in each of the research papers (Chapters 4-8). The aim here is to provide background to justify the approach taken to answering the research questions and the choice of methods.

2.2 Innovation Systems

The linear model of innovation, in which ideas are developed from laboratory to prototype to final commercialisation, often by a single inventor/entrepreneur, or within the one firm, has long been discarded, though it still has provides relevant insights (Balconi, Brusoni & Orsenigo 2010; Godin 2006). The systems approach has been defined in general terms as including "all important economic, social, political, organization, institutional, and other factors that influence the development, diffusion, and use of innovations" (Edquist, 1997, p.14). This approach to innovation has been developed through disciplines such as science policy studies, economic geography and sociology in a quest for a deeper understanding of the dynamics of how innovation processes occur (Fagerberg 2005). Models of innovation systems (IS) or systems of innovation (SI), which admit the complexity of innovation, and seek to understand the necessary environments and interactions for innovation to be successful have proven to be useful tools (Dodgson et al. 2011; Manjón & Merino 2012).

Innovation systems thinking had its genesis in the 1980s as an holistic attempt to "describe, understand, explain - and perhaps influence - processes of innovation" (Edquist 1997, p.2). Innovation systems are conceptual frameworks rather than theory, which seek to maintain conceptual ambiguity in an attempt to encompass all important factors in innovation (Edquist, 1997). Key aspects of innovation systems are the emphasis on institutions, the dynamic nature of actors within the system, and the boundaries that nevertheless allow a system to be defined.

The concept of institution is central to innovation systems, rather than being assumed, as in other approaches to innovation (Edquist 1997). Institutions have been described as identifiable organisations such as universities, financial organisations, and government agencies, formal frameworks such as legal systems, intellectual property protection systems, economic policies, or informal aspects such as common habits and established practices within an industry sector (Coriat & Weinstein 2004; Edquist 1997; Edquist & Johnson 1997). The institutional component of innovation systems has also more commonly been restricted to the intangible aspects of habits, norms, routines, practices, rules and laws, with the tangible aspects of the system, expressed as firms and non-firm organisations (for example, universities, government) being considered the organisational component (Edquist 2005). These are known respectively as soft and hard institutions.

The tangible organisational structures of firms and non-firm organisations may be considered to be ‘players’, ‘agents’ or ‘actors’ (Edquist 2005; Malerba 2005). Firms may be the producers of goods and services and also the users of those goods and services or their suppliers (Malerba 2005), which is why the generic term ‘actor’ is usually used. Actors are most often considered to represent institutions, or firms rather than individuals. Innovation systems are considered to be populated with heterogeneous actors.

The activities occurring within innovation systems are broadly directed at the creation, diffusion and exploitation of innovation, encompassing activities that extend beyond conducting research activities to the building of competence within firms and other organisations, creating and changing organisations and institutions to maximise innovation outcomes, as well as business services (Edquist 2005).

With such vague, conceptual definitions of systems of innovation, it may seem that every aspect of technology and innovation is connected, and to some degree this is true. However, boundaries may be set to define an innovation system, either spatially, sectorally, or in terms of activities (Edquist 2005). Spatial limitation may be to national or regional boundaries, sectoral limitation may be to a particular technological field and limitation by activity is a way of further limiting the other two boundary criteria. Aoki (2007) utilised game theory to explore the way that institutions change, defining a domain as a space in which an actor has motivation to obtain a social outcome and institutions as the expression of the equilibrium outcome of the game. From this perspective, boundaries can be framed to define a system of innovation in a way that suits the purpose of the analysis.

2.2.1 Systems of innovation

In practice, four approaches have been taken to approaching systems of innovation: the national, regional, sectoral and technological approaches.

2.2.1.1 National systems of innovation

The national innovation systems approach (Edquist 2005) to understanding the innovation of an entire country has arisen within the context of ‘science policy’ research (Fagerberg 2005) and was first formulated in 1995 (Edquist 1997; Sharif 2006). National approaches emphasise understanding the economic and other policy settings that maximize the macroeconomic impacts from effectively linking scientific discovery and invention with the application of those discoveries and inventions as innovations. National governments implement the results of this scholarship to stimulate innovation within their own country.

It has been suggested that national systems do not exist as such but rather can be considered to be an ecological framework for the development of local innovation systems (Metcalfe 2007). Ecologies consist of organisations and individuals who generate and hold knowledge and the innovation system describes the connections between these knowledge organisations and other actors at a regional (or local) level.

2.2.1.2 Regional systems of innovation

Regional innovation systems have become a subject for research (Lam 2005) as regional governments and organizations such as universities (Mowery & Sampat 2005) seek to stimulate the development of regional economies through policy or as the consequence of commercializing research. The study of innovation systems within sectors has sought to understand how innovation occurs in geographic clusters (Owen-Smith & Powell 2004; Singh 2008), with Silicon Valley in California and the Boston biotechnology cluster being two highly researched examples (Asheim & Gertler 2005).

2.2.1.3 Sectoral systems of innovation

A third approach has been to examine innovation within an economic sector. Sectoral innovation systems (SIS) are "composed of a set of new and established products for specific uses, and a set of agents carrying out activities and market and non-market interactions for the creation, production and sale of those products" (Malerba 2004, p. 16). Sectoral systems clearly are based on earlier work on technological systems (Breschi & Malerba 1997) but are more clearly focussed on those firms involved in innovation activities and competition between those firms in an innovation environment. The study of innovation systems within sectors has sought to understand how innovation occurs within and between firms within a sector of the economy, which may, or may not, be within geographic or national boundaries. SIS are acknowledged as a flexible, holistic and interdisciplinary approach to understanding innovation of products and services within an environment influenced by multiple actors and institutions (Edquist 2005).

Sectoral innovations develop around a particular problem or opportunity framed by contingencies (regulatory, cultural, technological) (Tether & Metcalfe 2004). By utilising game-theory as an approach to understanding innovation in institutions, Aoki (2007) introduces the domain as the unit of analysis in which games are played. This notion may also be useful to distinguish the various innovation 'games' that may occur within a SIS, variously overlapping and impacting on one another. It is possible also, that these domains may represent technologies, as they operate within a sector.

2.2.1.4 Technological systems of innovation

Technological innovation systems (TIS) may be described as a "network of agents interacting in the economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion, and utilization of technology" (Carlsson & Stankiewicz 1991, p. 94). A TIS is considered to contain all the components necessary to influence the innovation process for a particular technology (Bergek et al. 2008) and analysis may proceed from consideration of customers, products and/or technologies (Carlsson et al. 2002). Technological systems are considered to have the characteristics of economic competence (ability of firms to develop and exploit opportunities), clustering of resources and institution al infrastructure (Carlsson & Stankiewicz 1991) but not all technological systems have innovation as a purpose. The study of a technological system may clearly cross the boundaries defined by national and/or sectoral innovation systems (Markard & Truffer 2008) and the areas for research may be defined with differing levels of perspective, from the small scale niche to the broader scale regime of sectoral systems; the term 'socio-technical' may be used to describe the intersection. The domains defined within sectoral systems could clearly be technologies, and represent the identified intersection between sector and technology.

TIS approaches appear to have been useful in the analysis of emerging technologies that may be broadly applied across many industry sectors, such as energy systems (Suurs & Hekkert 2009; Suurs, Hekkert & Smits 2009), perhaps where a 'sector' has not yet developed.

2.2.2 Theories of innovation system failure

Hunt (2010, p. 173) cites the definition of Rudner (1966) that identifies theories as being systematically related statements that contain law-like generalisations and are able to be empirically tested.

Various diagnostics and heuristics have been developed in an attempt to understand, and change the direction of innovation within innovation systems. Innovation systems scholars have largely rejected the market failure theory. Two approaches to understanding the operation of innovation systems, their problems and potential solutions have been proposed.

Within the sectoral innovation literature, a frequently cited paper presenting a framework to understand sectoral system failure has been proposed by Klein Woolthuis, Lankhuizen and Gilsing (2005), while within the TIS literature, a framework of innovation system failure has been proposed by Bergek and others (2008), also frequently cited. Neither approach claims their work to be the development or espousal of theory; rather, they are suggested as approaches to analysis and policy intervention based on empirical studies.

The multi-level perspective and strategic niche management are often cited (Geels 2002; Le Masson et al. 2012; Lovio & Kivimaa 2012; Markard & Truffer 2008) as approaches to understanding innovation but these approaches have been applied to radical innovations and socio-technical or sustainability transitions (Coenen & Díaz López 2010).

2.2.2.1 Market failure theory

According to economic theory, perfect competition leads to an optimal allocation of resources (Arrow 1962) and market failure thus occurs when markets fail to allocate resources to their most valuable use (Rama & Harvey 2009). The assumption of perfect competition and allocation of resources:

> prohibits uncertainty in the production relations and in the utility functions, and it requires that all the commodities relevant either to production or to the welfare of individuals be traded on the market. This will not be the case when a commodity for one reason or another cannot be made into private property (Arrow 1962, p. 609).

These assumptions are not easily met in a sector or technology that is dynamic and innovating. Food safety is affected by market failure (Crutchfield et al. 2001; Rama & Harvey 2009).

The inadequacy of market failure to explain the inability of markets, with or without government intervention, to promote innovation is a fundamental premise of the innovation system literature (Bleda & Del Río 2013; Sharif 2006). Early proponents of innovation systems have declared that "the conventional approach to public [innovation] policy - which is based on market failure - is no longer adequate" (Carlsson & Jacobsson 1997, p. 299). Later scholars have continued to assert that "scholars on innovation and technology have almost completely rejected the market failure approach as a basis of policy action" (Bergek et al. 2008, p. 407). A more balanced view might be that

> market failure is too narrow a perspective to provide an adequate analytical or empirical basis for innovation policy. The central ideas of the market failure doctrine are rounded [sic.] in the theory of a perfect competition and the fundamental welfare theorems that link this idea to the optimum allocation of resources in an economy.... The problem that now arises is that these “failures” are an intrinsic consequence of the process of innovation itself and could only be eliminated if innovation ceased (Dodgson et al. 2011, p. 1146).

Innovation systems do admit that market failures may play a part in innovation failure, and that both innovation systems and markets require analysis. In fact, the TIS functional failure framework specifically recognises the formation of markets as an essential function for innovation systems (Bleda & Del Río 2013), and sectoral innovation system scholars have added market failures to the structural failure framework (Klein Woolthuis 2010).

2.2.2.2 Structural failure framework

Klein Woolthuis, Lankhuizen and Gilsing (2005) base their ideas, identified as the structural framework (Bergek et al. 2008; Wieczorek & Hekkert 2012), on the assumptions of SIS: that innovation does not occur in isolation, and that institutions are critical, and evolutionary processes play an important role in determining innovation outcomes. They acknowledge that imperfections can occur and seek to define these system imperfections, problems, or failures. The key distinction in their work is between system rules (institutions) and the actors in the system. The authors claim that this approach allows the analysis, justification of policy intervention and evaluation of innovation systems, identifying the causes of failures and the actors who need to be addressed to make change. This framework can be considered to contain theory because these propositions are all related to the success of an innovation system, are generalised to sectoral innovation, and are open to evaluation.

The framework of Klein Woolthuis et al. is based on the work of others who have made empirical observations and described the 'imperfections' of the innovation systems studied. Klein Woolthuis cites the work of Carlsson and Jacobsson (1997) who described failures in technological systems as failures of networking, institutions or systems (actors, regional or national systems), Smith's (1997) description of infrastructural and institutional failures and Edquist et al. (1997) description of institutional and interactional failure. One significant contribution of Klein Woolthuis' was to consolidate the described imperfections, and standardise their description. The second was recognising the distinction between 'rules' and 'players' which allowed system problems to be described in two dimensions, thereby, allowing problems to be clearly defined, and amenable to rational policy response.

In the first dimension Klein Woolthuis et al. define various types of actors:

- demand (consumers, large buyers)
- companies (large firms, multi-national corporations, small to medium enterprises, start-up companies)
- Knowledge institutes (universities, technology institutes)
- third parties (banks, venture capitalists, intermediaries, consultants, sector organisations employers)

though this list is not indicated to be exhaustive. Policy makers are also actors, but, in this model, are not defined as such because they are assumed to be the system analyst and policy developer.

In the second dimension rules (institutions) are categorised as:

- infrastructural (information and communication technology, energy supply, roads, railroads, telecommunications, scientific and applied knowledge and skills, testing facilities, possibilities for knowledge transfer, patents, training, education)
- institutional (hard: formal written consciously created, and soft: informal, spontaneous and unwritten 'rules of the game')
- interaction (weak network failure due to poor connectivity between actors, strong network failure, such as group of actors dominated by one partner, an internal orientation and failure to seek new approaches)
- capabilities of the actors (lack of competence, capacity, or resources).

This 'SI-policy framework' is depicted by Klein Woolthuis and others (Arduino et al. 2013; Janssen 2009; Klein Woolthuis, Lankhuizen & Gilsing 2005; van Mierlo, Arkesteijn & Leeuwis 2010; van Mierlo et al. 2010) as a table (Table 2.1).

Table 2.1 The sectoral (structural) innovation system failure framework
(Klein Woolthuis, Lankhuizen & Gilsing 2005). Weaknesses in the system are identified as being at the intersection of an actor (the columns) and the system rules (the rows)

Actors (missing actors) **Rules (system failures)**	**Demand** • Consumers • Large buyers	**Companies** • Large firms • MNCs • SMEs • Start-ups	**Knowledge Institutes** • Universities • Technology institutes	**'Third parties'** • Banks, VCs • Intermediaries, consultants • Sector organisations, employers
Infrastructure failure: ICT, roads, railroads, telecom,...				
Institutional failure • Hard: laws, regulations ...				
• Soft: norms, values ...				
Interaction failure • Weak network failure				
• Strong network failure				
Capabilities failure				

This framework has been used, sometimes with modification, by various authors in the analysis of SIS in Australian red meat (Pitt & Nelle 2008), Dutch agriculture (van Mierlo, Arkesteijn & Leeuwis 2010), Dutch healthcare (Janssen 2009), Dutch construction (Klein Woolthuis 2010), Chinese information and communication (Zhang & Liang 2012) and Greek sea-port (Arduino et al. 2013) sectors. A number of authors comment positively on the usefulness (Janssen 2009), comprehensiveness (Pitt & Nelle 2008) and necessity (Klerkx & Leeuwis 2009) of such a framework. The wide scope of the framework is seen as providing valuable insight into interactions between entrepreneurs and the system (Janssen & Moors 2013). The framework was considered to be useful for mapping drivers and barriers to technology transfer for and helping to uncover the source of both successes and challenges in an innovation system (van der Vlies & Felix 2013).

The categories and identity of actors has been added to by several authors to acknowledge government (regulator, national, local) as a key actor group (Klein Woolthuis 2010), value chains (Pitt & Nelle 2008) and lead clients (Klein Woolthuis 2010) as demand creators, entrepreneurs and professionals (Janssen 2009) who may act like companies, and trade unions (Pitt & Nelle 2008) who may be significant third parties. Lamprinopoulou et al. (2014) suggest a typology of system actors in four domains: research, intermediaries, enterprises and innovation influencers.

The list of failures has been added to and redefined by several authors (reviewed by Negro et al. (2012)). Adaptive failures have been suggested as an additional failure type. Pitt and Nelle (2008) identify three kinds of adaptive failures: lock-in, internal orientation myopia, and transition. Lock-in failures were dismissed by Klein Woolthuis and Negro et al. as the result of other identified system failures, such as strong or weak network failure or a capability failure. Similarly, myopia is seen to be a type of strong network failure where insufficient attention is paid to development outside the network (Klein Woolthuis, Lankhuizen & Gilsing 2005). Transition weakness could be due to a weakness in any of the other elements. Therefore, all these adaptive failures may be considered as indicators or symptoms of other system failures. Pitt and Nelle (2008) also identify 'sector culture failure' which they characterise as lack of entrepreneurial orientation, inability to enter a new technological domain and lack of support for innovative start-ups. These failures may be soft institutional or capability failures. A group of transformational failures have also been identified by Weber and Rohracher (2012) that are relevant to socio-technical transitions.

Market failures have been specifically restored to the framework (Klein Woolthuis 2010; van Mierlo et al. 2010; Weber & Rohracher 2012) which results in a broad systems failure framework, since structural innovation failures were seen as supplementary to market failures (Klein Woolthuis, Lankhuizen & Gilsing 2005).

In addition to identifying and refining the lists of actors and failures, the use of the theory has been further developed in other ways. Pitt and Nelle (2008) add 'dimensions' to each failure and evidences for each category of system failure. This level of detail is a step towards clear criteria for the diagnosis of failure. van Mierlo et al. (2010) discuss the use of 'system instruments' that are interventions to address the system imperfections or failures. Arduino et al. (2013) points out that the analysis is conducted at a point in time, and that a temporal dimension in the analysis would lead to an understanding of how the innovation system needs to respond to stages of development. They also suggest that there are both positive and negative correlations between the performance of the innovation system and the activities of an actor towards a system element, rather than just thinking about 'failure' (Arduino et al. 2013). The basic "policy framework" has been enhanced with systems involving these latter two aspects with a descriptive focus on the leader of the innovation (public or private) and the type of innovation (technological, managerial or cultural) to produce a "Systems of Innovation Framework" (Roumboutsos, Kapros & Vanelslander 2014).

The sectoral (structural) failures framework has been critiqued by several authors for lack of enabling tools. Bergek et al. (2008) and Hellsmark and Jacobsson (2009) suggest that the structural theory does not adequately explain the dynamics of what occurs within an innovation system or whether actors are a positive or negative influence. Dantas (2011) suggests a lack of ability to explain system performance and points out that organisations may play multiple roles within the system, and an analysis focussed on organisations may not acknowledge this complexity. Jacobsson and Bergek (2011) criticise the theory for the lack of diagnostic indicators of failure, a criticism with which Wieczorek and Hekkert (2012) agree, adding that there is little literature on how to identify and address problems. Chaminade and Edquist (2006, 2010) claim that, despite the application of the SI approach little is known about how the system actually operates.

2.2.2.3 Functional failure framework

Bergek et al. (2008) provide an approach to analysis of innovation failure arising from the TIS literature, which has been identified as the functional approach. While these authors acknowledge the "need to supplement a structural focus with a process focus" (Bergek et al. 2008, p. 409) their approach is otherwise independent of Klein Woolthuis et al.. Bergek et al. claim that certain processes, or functions, need to occur for innovation to occur. They also suggest that certain inducement or blocking mechanisms may act to encourage or hinder the innovation process. Government policy must be directed towards overcoming these blocking mechanisms, if innovation is to occur. This framework contains theory because these propositions are all related to the success of an innovation system, are generalised to technological innovation and are open to evaluation.

The work of Bergek et al. (2008) is within the scope of innovation systems literature, particularly depending on the understanding of technological innovation systems (Carlsson & Stankiewicz 1991). The framework draws on work on an understanding of entrepreneurs operating in a socially constructed systems (van de Ven 1993), coalitions advocating for change (Sabatier, PA 1998), and strategic niche management (Kemp, Schot & Hoogma 1998). The intent of this framework is to describe the functions of innovation systems, and how these operate dynamically (that is, over time). This approach to the process of innovation had the stated intent of supplementing the structural focus. It is based on several previous publications proposing a list of functions operating within innovation systems, but did not claim to provide a complete list.

A very similar list was published by Hekkert et al. (2007) at about the same time as Bergek et al. (2008) but Bergek et al. has been described as the 'best attempt ... to integrate the different concepts.' (Wieczorek & Hekkert 2012, p. 75). (Table 2.2).

The framework of functional problems of innovation systems, focuses on TIS and aims to produce an analytical framework useful for policy makers. The structural components of the TIS are identified (actors, networks, institutions) and key processes or 'functions' operating within TIS are identified. The functions are seen as being characteristic of the TIS rather than being linked to a particular actor, and this functional pattern can then be assessed, the factors 'inducing' or 'blocking' the system can be diagnosed, as a basis for policy intervention.

The benefit of this analysis is that the functional framework is explicit about the functions of the innovation system which allows for the identification of policy problems, though the papers of Bergek et al. and Hekkert et al. don't claim to provide comprehensive lists of functions.

A functional failure analysis has been used to analyse the TIS for alternate transport in Netherlands (Farla, Alkemade & Suurs 2010), microgeneration in the United Kingdom and Germany (Praetorius et al. 2010), combined-heat-and-power systems in the United Kingdom (Hudson, Winskel & Allen 2011), renewable electricity technologies (del Río & Bleda 2012), sustainable energy systems in United Arab Emirates and Saudi Arabia (Al-Saleh & Vidican 2013; Vidican et al. 2012), and Chinese wind power (Gosens & Lu 2013). Various authors have noted that this approach is useful for technological policy research (del Río & Bleda 2012 quoting Coenen and Diaz), encourages explicit conceptualisation of actors' strategies (Truffer & Coenen 2012), is useful (Praetorius et al. 2010), and allows for a comprehensive analysis of multiple influences (Aláez et al. 2008). A TIS failure analysis has been used to analyse a sectoral system, claiming it to be flexible and useful (Gabaldón-Estevan & Hekkert 2013). Apart from retrospective analyses, some have promoted the combination of functional analysis and participatory stakeholder dialogue to assist in framing public debate (Breukers et al. 2014).

Some authors (Bleda & Del Río 2013; Weber & Rohracher 2012) have added market failure categories to complement the functional failures. Cagnin et al (2012) have omitted the legitimization function and provided additional insight into the definition of functions (Table 2.2). McDowell et al (2013) points out that functional failures need to be examined not only in the formative and growth phases, but also in the transfer phase of a technology. The analytical ability of the theory was further developed by the identification of events that may indicate that certain functions are operating within the system (Suurs & Hekkert 2009) and by the development of diagnostic questions that could be used to determine the action of system functions (Wieczorek & Hekkert 2012). Lamprinopoulou et al (2014) consider separately the provision of funds from mobilising of other (in kind and human) resources. Al-Saleh and Vidican (2013) use a 'force field' analysis to present the action of inducement and blocking mechanisms for system functions.

Table 2.2 The functions of a technological innovation system

Hekkert et al. (2007)	Bergek et al. (2008)	Cagnin, Amanatidou and Keenan (2012)
Knowledge development - R&D and knowledge development are prerequisites with the innovation system - 'learning by searching' and 'learning by doing'	**Knowledge development and diffusion** - the knowledge base, its evolution, and how knowledge is diffused and combined in the system	**Nurture knowledge development** - research and development, knowledge of production design and markets
Knowledge diffusion through networks - exchange of information, especially between R&D and government competitors and market		**Promote knowledge diffusion** - mediated through networks, supply chains, standards
Guidance of the search - choices are made from various technological options for further investment, involving industry, government, markets	**Influence on the direction of search** - the incentive and/or pressures for organisation to choose to enter the TIS and mechanisms having influence of the search within the TIS	**Guide direction of the search and selection** - guiding actors to select options for investment through visions, expectations, regulations, policy, activities of lead users
Entrepreneurial activities - turning the potential of new knowledge, networks, and markets into concrete actions to generate - and take advantage of - new business opportunities	**Entrepreneurial experimentation** - investigation of new technologies and applications in an attempt to overcome the uncertainties that exist within a TIS	**Facilitate experimentation and learning** - entrepreneurial experimentation, generating variety, social learning
Market formation - regulation and formation of markets that will allow new developing technologies to continue to develop	**Market formation** - the development of a market through capability to, and actual articulation of demand, price/performance, reduction of uncertainties	**Promote market formation** - create spaces through policies, standards or regulations that nurture demand for innovations
Creation of legitimacy / counteract resistance to change - becoming part of an incumbent regime or overthrowing it; development of advocacy coalitions for processes of change	**Legitimation** - social acceptance by relevant actors	
Resources mobilization - Supply of resources, both financial and human capital for innovation	**Resource mobilization** - the ability of the TIS to provide competence/human capital, financial capital and complementary products, service and network infrastructure	**Develop and mobilise resources** - human resources, capital, infrastructure
	Development of positive externalities - entry of new firms may resolve uncertainties, about technologies and markets, may legitimate the TIS either directly or through strengthening the power of advocacy coalitions and may allow new combinations to arise	

It is understood and accepted that "functions influence each other" (Hekkert et al. 2007, p. 425) with the earlier, and therefore more fundamental, functions being dubbed "motors of change" (Hekkert et al. 2007, p. 426). Guidance of the search, leading to knowledge creation, and entrepreneurial activities such as lobbying for more research (legitimation) or market formation are the key functions that lead to the successful operation of a TIS. Others consider that the motors of change may be the entrepreneurial motor, the system building motor and the market motor (Suurs et al. 2010). The identification of the influential, or driving, functions is a challenge that has only been approached qualitatively (for example, Bergek et al. (2010)) because the benefit of a function can only be assessed by the effect it has on the functioning of the whole system (Thurner & Proskuryakova 2013). It has been acknowledged that further work is required (Bergek et al. 2010). Functional analysis of the developing TIS for solar energy in the Middle East (Al-Saleh & Vidican 2013; Vidican et al. 2012) has suggested that, within this culture, the driving function is 'guidance of the search' which follows a "top-down route, which is the preferred method for change in Arab culture" (Vidican et al. 2012, p. 186). These authors argue that "one cannot overemphasize the futility of the search for a single pattern of functional interrelations to assure a well-performing SI" (Vidican et al. 2012, p. 186).

Weber and Rohracher (2012) suggest that the functional approach is limited because it is focussed on technology-specific developments and does not consider the transformation of broader systems to meet challenges facing society such as climate change. Consequently, they propose additional, "transformative system", failures.

Some have criticised functional failure framework for not defining a geographical boundary when considering technologies and thereby not considering the differences that may arise between countries in the way that a technology is developed (del Río & Bleda 2012; Hillman et al. 2008; Truffer & Coenen 2012). Schmidt and Dabur (2014) have explicitly added the role of national borders (effect of national institutions) and international technology transfer to their functional analysis of TIS. Others have found that the development of the theory on the identification and action of motors has been insufficient, suggesting that entrepreneurship alone is an insufficient motor (Hudson, Winskel & Allen 2011) and pointing to the need for more attention to the inter-relation of functions (del Río & Bleda 2012). Criticisms also point to the need for some combination of structural and functional frameworks through identification of the need to consider dynamics that may occur outside the TIS (Hillman & Sandén 2008), understanding how a technological demonstration program may articulate to a position within a broader market and policy domain (Lai et al. 2012), and the need to consider the capabilities and roles of actors, networks and institutions (Hudson, Winskel & Allen 2011; Wieczorek & Hekkert 2012).

Despite the many studies utilising the framework some (Mahroum & Al-Saleh 2013) claim that the framework has not been operationalised sufficiently for policy analysts to work with the suggested tools.

2.2.2.4 Combining structural and functional failure frameworks

Vidican et al. (2012), studying the emerging solar energy sector in the United Arab Emirates, have argued that, when investigating the emergence of new industries, it is necessary to consider the multiple knowledge bases and technological bases that contribute to the development of a sector, rather than taking a functional failures approach exclusively.

Wieczorek and Hekkert (2012, p. 75) suggest that functional analyses alone is incomplete. They note that Bergek's model is the "best attempt ... to integrate the different concepts" but does not need to utilise the concept of inducing and blocking mechanisms since these are similar to the problems identified by Klein Woolthuis et al. as systemic (structural) problems. They also note that, Bergek et al. do not elaborate on the capabilities of actors, network and institutions. Wieczorek and Hekkert suggest that the theories of Klein Woolthuis and Bergek can be combined, since they have the same scholarly foundation.

Lamprinopoulou et al (2014) proposed and exemplified an integrated framework utilising both structural and functional analysis to compare two national agricultural innovation systems which were then used to perform a transformation oriented analysis (Weber & Rohracher 2012) to consider how these innovation systems might be further developed. The authors found that the tools used of an integrated framework of structural and functional analysis were complementary and appropriate to provide a holistic perspective.

2.3 Intermediaries

Innovation systems operate as networks of heterogeneous actors, both firms and non-firm, with complementary skills and roles (Malerba 2004). Networks may develop for the principal benefit of a single actor, or may potentially benefit all actors. Strategic business networks, may develop intentionally, for purposes other than innovation, including access to resources/capability, development of capability and market access (Möller, Rajala & Svahn 2005). When networks exist, the way that these networks function becomes a question of interest to scholars, which has led to identifying the role of 'intermediary'. The role has received little attention in the sectoral and technological innovation systems literature, so it is of interest to understand how the intermediary role may interact with the operation of an innovation system. The definition, identification and function of intermediaries will be reviewed.

2.3.1 Definition of intermediary

Various terms have been used for those actors (individuals or organisations) that have a role in bringing together people and/or technologies: integrators (Hobday, Davies & Prencipe 2005); intermediaries (Howells 2006); brokers (Batterink et al. 2010); and orchestrators (Dhanaraj & Parkhe 2006). These roles may vary in detail, but there is a commonality - bringing together people, and/or organisations and resources. 'Intermediary' may be the most general term for these innovation system actors (Howells 2006).

2.3.2 Identification of intermediaries

Many actors in an innovation network can fulfil the role of intermediary.

A "hub firm" within a network may take the role of manager, orchestrator or coordinator of the network (Dhanaraj & Parkhe 2006; Ritala, Armila & Blomqvist 2009) providing leadership and strategic direction to the innovation system.

Service providers may serve as intermediaries as through their business activities. They may co-produce innovation with their clients in the case of knowledge intensive business services such as information technology and engineering service firms (Den Hertog 2000). They may provide web-based services bringing together those with needs and those with potential solution (Colombo, Dell'Era & Frattini 2015). They may also bring together different actors in the physical environment (Batterink et al. 2010).

Organisations with socialised funding and a policy mandate may act as intermediaries. The rural research and development system in Australia has a recognised integrating function:

> ...there has been considerable collaboration and coordination between those procuring and supplying rural R&D. Indeed, one of the strengths of the RDC model has been its system integrating role that has both fostered collaborative research work and helped to prevent unproductive duplication of research effort (Australia. Productivity Commission 2011, p. 83).

Industry member-based organisations have been identified as key actors in the intermediary role in the development of national innovation systems (Watkins et al. 2015) and government agencies (including semi-autonomous, owned companies, or foundations) have been identified as intermediary organisations in technological transitions, particularly in areas such as sustainable energy (Kivimaa 2014).

Individuals are also recognised as intermediaries. Pitt (2007) identified the innovation integration function as a key responsibility in a SIS, suggesting that the role is sometimes played by individual managers. Ritala, Armila and Blomqvist (2009) suggest that both individuals and organisations can have the requisite capabilities to be effective intermediaries**.**

2.3.3 Functions of intermediaries

The functions of intermediaries in innovation networks and the skills required may be considered as those common to any network, and those that may be more specific to networks with an innovation purpose.

Systems integration developed in the 1940s as disparate technologies were being combined into new products, particularly military hardware. The intermediary role in systems integration is to "define and combine together all the necessary inputs for a system and agree on a path of future systems development" (Hobday, Davies & Prencipe 2005, p. 1110).

General network management functions are required, implied by the formation and membership of the network, through management functions such as planning, mobilising resources and controlling (Järvensivu & Möller 2009). Integrators possess the organizational boundary spanning capabilities that give it prominence and power in the innovation system (Dhanaraj & Parkhe 2006); often allowing smaller more agile firms to play a significant role in innovation system integration (Sabatier, V, Mangematin & Rousselle 2010).

In networks with an innovation purpose, orchestration is proposed to consist of managing knowledge mobility, managing innovation appropriability and fostering network stability (Dhanaraj & Parkhe 2006). The coordination of the innovation system network requires enabling leadership and strategic coordination rather than management since it is composed of a range of independent and autonomous organizations with their own strategic objectives (Ritala, Armila & Blomqvist 2009).

Specific roles for intermediaries in innovation networks include: network formation, articulation of needs to be met through innovation, and innovation process management (Klerkx & Leeuwis 2009). When these functions are specifically addressed by the innovation intermediary, value is created for the network (Batterink et al. 2010). Pitt (2007) identified the significant benefit in integrating a firm's internal capabilities with external scientific and technological capability and that communication between firms and researchers will facilitate the commercialisation of research and development outputs.

A number of specific functions may be undertaken by intermediaries for individual firms, whether they are part of a specific innovation network or not, that specifically service innovation processes including technology scanning, dealing with regulation, intellectual property protection, commercialisation and evaluation (Howells 2006).

3

Methodology and methods

3.1 Introduction

This chapter considers the approaches that could be taken to answer the research questions. The methodological landscape and methods employed in the economic, business and sociological approaches to innovation studies are considered. It also provides detail on the data collection and analytical methods that are only briefly described in journal articles (Chapters 4-8). The actions taken to deal with ethical issues are also considered and discussed.

3.2 Methodology

Research methodologies, as they relate to social phenomena, involves thinking about the process of research and how it is positioned philosophically and the assumptions made when answering the questions posed (Creswell 2007).

The research conducted is within the domain of qualitative research. Mason (2002) identifies three aspects of qualitative research that define it as qualitative:

- an approach that is concerned with how the social world is interpreted, understood, or constituted
- methods of data generation sensitive to the social context
- methods of analysis and explanation that acknowledge complexity, detail and context.

The approach taken to the work described in this thesis is essentially qualitative, though the analytical methods have quantitative aspects. Methodology is a pragmatic response to select approaches that the researcher believes will be useful in answering research questions in a way that is meaningful to a particular audience. Therefore, an understanding of the constitution of the social world (ontology) and how that may be explored through data generation and analysis (epistemology) is presented as a first step in justifying the methods chosen.

3.2.1 The world (ontology)

Innovation occurs in an environment that is physical, socially interactive, and at certain points explicit and knowable from the outside. Many people are involved, usually representing an organisation and they all playing different roles, they will know different things or have different perspectives.

Scientific quantitative research, and modernist qualitative research, derives from a philosophical base that holds that knowledge rests on a set of truths, such as a fixed, unchanging reality, from which beliefs may be logically deduced (Guba & Lincoln 2005; Hughes & Sharrock 1997). This has been the prevailing philosophical paradigm since the 17th century (Hughes & Sharrock 1997) for both science and social science research.

Within modern thought (post 17th century) there are a number of paradigms (ontologies) that are appear to be relevant to thinking about how innovation works. Scientific research is predominantly positivist or post-positivist. Positivism takes the position of describing objectively ‘real’ reality which is knowable to the observer, who is completely separate from the phenomenon or object of study (Guba & Lincoln 2005), whereas post-positivism acknowledges the flaws in observational methods, lack of total objectivity and therefore, that reality is imperfectly knowable (Denzin & Lincoln 2005; Guba & Lincoln 2005). Much of the research in food safety is post-positivist. Some qualitative research has also taken a positivist or post-positivist ontological position. Research on innovation systems is within a discipline of science policy and innovation studies (Martin 2012), which Godin (2012) notes is descriptive, seeks to develop theory and is concerned with policy issues. A post-positivist ontological position is suitable for this research.

3.2.2 Knowing the world (epistemology)

What can be known and how might we know something about the operation of innovation systems? Some knowledge will be quite objective, for example, the research organisations and their staff who worked on research projects as indicated by contracts, publications and other records. Sometimes it may be obvious that innovation has occurred, such as the implementation of regulations based on scientific research that causes product to be safer. This approach to gaining knowledge is within the scientific, empiricist (objectivist) epistemological tradition (Hughes & Sharrock 1997).

Questions about how some actors participated in projects, and how they contributed to the outcomes, or how decisions were made, do not have an objective answer. The answers are contained in the recollections, practices and beliefs of individuals and groups of individuals, sometimes with consensus and sometimes not. This is a subjectivist epistemology in which knowledge is created by the researcher and the participants together forming understandings of the reality (Denzin & Lincoln 2005).

Knowledge will be co-created between the researcher and project participants (and possibly others) who, in many cases, are peers, contractors, mentors and professional colleagues. This is potentially difficult terrain to cross in which control is shared between researcher and participants (Guba & Lincoln 2005) and power issues will need to be addressed to ensure the validity of data (Dowling 2010).

3.3 Method

The methods employed throughout this research are presented here, both to justify the choice of methods and provide detail missing from research publications (Chapters 4-8). A description of the overarching case study method is followed by a description of survey methods and then the use of the Qualitative Comparative Analysis (QCA) method for analysis of data collected by the survey. Case studies, surveys and QCA are appropriate within the ontological and epistemological framework of this study as well as the pragmatic needs of how data can be collected, the small number of cases for analysis and the desire to test IS theory.

3.3.1 Case study method

The approach chosen for conducting the research is that of case study. The suitability of case study methods for answering the research questions is explored, before considering the design of the case study and selection of cases.

A case study may be defined as an empirical inquiry that investigates a contemporary phenomenon in depth and within its real-life context, especially useful when the boundaries between phenomenon and context are not clearly evident (Yin 2009).

Case studies have been variously described as a research strategy (Denscombe 1998), and as a process of enquiry (Stake 2005). Here, the case study is a strategy for addressing the research questions. Case study method provides a framework for enquiry within which various other methods may be utilised. Case studies, are suitable for situations in which an experiment cannot be conducted; and in any case, may be more suitable for explaining ‘how’ or ‘why’ than an experimental design that may establish the impact of a particular treatment, but be unable to discern the reason (Yin 2009).

The cornerstone of case study method is the ‘unit of analysis’ or ‘case’, which needs to be chosen in a way that will help to answer the research question. It may be possible to answer the research question with a single-case, or multiple cases may be required (Stake 2005). A series of case studies allows similarities and differences to be observed, developing and testing of theory and opportunities for understanding gained in one case to be extended to subsequent cases studied. The cases may be in different contexts, or there may be multiple units of analysis within a single case. The choices may be based on circumstance, but ideally, should be based on the contribution that is made to answering the research question (Yin 2009).

3.3.1.1 Case study method in innovation systems research

A case study approach is common in business studies (Yin 2009), including innovation studies.

Case studies have been used in the analysis of sectoral systems by Klein Woolthuis Lankhuizen and Gilsing (2005) demonstrating failures in the SIS for international rail transportation of agricultural products and for development of e-commerce systems.

Case studies have been positioned as central to the understanding of TIS failure. Bergek *et al.* (2008) described an approach to case studies of TIS. The approach presented was intended for the analysis of a TIS, the detection of problems and taking action to address them through policy. Case studies examining a TIS, being a technology in a single country have been performed (Suurs & Hekkert 2009) and cases have also been compared and contrasted (Negro, Suurs & Hekkert 2008; Suurs, Hekkert & Smits 2009).

These examples demonstrate that qualitative case studies are an acceptable approach and are being used as single and multiple case studies in innovation research, but there have been no study of as large a number of case studies as proposed here.

3.3.1.2 Case study design

In developing a strategy for answering the research questions through case studies, the case study design is critical (Yin 2009).

The research questions are about the ability of theories to explain innovation within sectors and technologies, their applicability and implications for innovation management. To test the theories, multiple cases would be required so that testing would be thorough, and to control for factors that may be outside the scope of the theories, working within a single sector and technology and therefore potentially contributing to analytical confusion. So, the unit of analysis is a project. The chosen cases are expected to lead to an understanding of projects as they pertain to the research question. This design corresponds to Yin’s (2009) definition of a holistic (that is, only one unit of analysis), multiple-case (that is, multiple contexts and cases) design.

Defining the cases in this way, suggests that individual cases will be analysed to provide data about the theories, and then comparisons and contrasts will emerge in a further round of analysis of the individual cases (Yin 2009).

Multiple-case designs are considered to yield conclusions that are more compelling and robust than single-case designs. The cases are replications of one another, which is analogous to conducting multiple experiments (Yin 2009) and allows opportunities not only to ensure that the cases are representative (typical), but also provide an opportunity for learning by inclusion of extreme cases (Denscombe 1998).

3.3.1.3 Selecting cases

In answering the research questions through case studies, the selection of cases for the case study is also critical (Stake 2005).

Multiple-case studies consider cases within different contexts. Projects may be chosen from within the same national (Australian), sectoral (red meat), and technological (food safety) innovation system, conducted by a single organisation, over a defined period of time. There are also a number of uncontrolled factors such as projects being conducted on different topics, by several research organisations, with some differences in the contractual arrangements, explicit or implicit consultation arrangements with stakeholder committees, and required minimum level of engagement with industry. This variety provides opportunity to select cases that will provide data for analysis that will allow answer to the research questions.

The population of projects under study was defined as those meeting three criteria:

- food safety projects (consisting of one or more contracts that lead to a single output, or outputs that build on one another directed towards a single industry application) of the Australian red meat industry and managed by MLA
- research starting date after 1 January 2000 and a research finishing date before 31 December 2012. (Choosing end of 2012 would allow some time for applications of the research projects/work to emerge before the survey date of January - March, 2015)
- some level of expectation by the research manager of MLA that innovation was a desired outcome at commencement and some output from the contract/s to show that there was technical success (contracts that do not meet this criterion might be considered to have 'failed' technically, and do not need to be included, because we wish to understand how the output of contracts was utilised to contribute to an innovation).

A description of the project was developed because the definition of a project is somewhat arbitrary, there is a tendency to associate 'project' with 'research contract' which would lead to a narrow focus for responses, and because respondents' memories may have faded (Groves et al. 2009). A description of each project was prepared (Appendix 1) from MLA files, supplemented by advice from MLA managers, technical consultants and research organisation personnel listing:

- contract names and numbers
- start and finish dates of contracts
- objectives, intended/desired innovation (if any)
- outputs in terms of project reports, industry reports, peer-reviewed publications,
- names of researchers and others involved in conducting, steering, commenting, reviewing, or applying results of the project

- outcomes of the project for industry - innovation/application of the outputs of the project
- identifying MLA webpage describing the project (where possible).

Forty-one projects were identified meeting the above definition. This is not a high number of projects, thus, a census could be conducted, by including all projects in the study.

3.3.2 Survey method

Surveys are well-accepted method of collecting data and are suitable for a subjectivist epistemology. The method described here is based on the iterative application of the stepwise approach promoted by a number of texts establishing principles and applicable approaches (Fink 2003b; Fowler 2014; Groves et al. 2009) and on the need to measure the parameters required to answer the research questions.

3.3.2.1 Study design

The survey collected data from a number of people for each project that were then used to characterise the project and used to answer the research question. In a sense, this was a case-control design, collecting data retrospectively in an attempt to explain a phenomenon by comparing two groups, and attempting to guard against the influence that extraneous (confounding) variables may have on the outcome of analysis (Fink 2003a). The two groups (cases, controls) consisted of projects, determined by survey respondents, to have resulted in innovation, or not.

The survey instrument

- described the project
- determined the respondents opinions about whether innovation occurred
- determined the respondents opinions about the elements of innovation systems present/operational in each project.

Cases and controls were defined by responses to the survey instrument. Of the 41 identified projects it was not known, prior to analysis, in how many an innovation outcome was achieved.

3.3.2.2 Measuring innovation

Much data collection by national statisticians and Organisation for Economic Co-operation and Development measures the inputs to the innovation process (Cornell University, INSEAD & WIPO 2015; Organisation for Economic Co-operation and Development & Statistical Office of the European Communities 2005). Identifying innovations is a relatively easy task, and suited to analysis at the project level. However, while successful innovations are identified as such, new ideas that are pursued but are unsuccessful innovations are identified as "mistakes" (van de Ven & Angle 2000). Therefore, it may be necessary to also measure the potential for future innovation coming from a project.

Schumpeter defined five types of innovation: new products or new qualities of products, new processes of production, new sources of supply, the exploitation of new markets and new organisational models for business (Schumpeter 1934). Over time these types have received modernised definitions (Organisation for Economic Co-operation and Development & Statistical Office of the European Communities 2005), but these categories are still considered to define the scope of innovation. Significantly, the definition of innovation includes the criterion of "new (or significantly improved) to the firm" (Organisation for Economic Co-operation and Development & Statistical Office of the European Communities 2005, p. 46), which indicates the need for application of the new development, and also that the knowledge that may be well known and previously applied by others.

Survey respondents provided an opinion about whether innovation occurred by asking a series of questions that identified the types of innovation believed to occur. In case there was delay in innovation occurring, or additional potential for innovation arising from a project, respondents were also asked whether innovation may arise in the future in each type of innovation. For each of the five types of innovation, indicator questions were developed, contextualised to the sectoral and technological system (Appendix 2).

3.3.2.3 Measuring innovation system elements

Due to the descriptive approach taken to innovation systems, measurement systems have not been developed to determine the presence or operation of individual innovation system elements. A measurement instrument must be constructed to determine, for each project, the elements of both the structural and functional theories that were present/operational in the project.

Following an analysis of the literature (Table 3.1), the elements of the theories were developed into the items (indicators) represented by questions in the survey instrument (Table 3.1 and Appendix 2).

Table 3.1 Explanation of Innovation System elements and survey instrument statements

Theory	Element	Explanatory material	Survey instrument statements
Structural	Presence of actors	Various actors may be missing from an innovation system: demand companies (firms / value chains) knowledge institutes third parties (Klein Woolthuis, Lankhuizen & Gilsing 2005) Relevant actors may be absent: Civil society Companies Knowledge institutes Government NGOs Other parties - legal organisations, financial organisations/banks Intermediates, knowledge brokers, consultants (Wieczorek & Hekkert 2012)	Actor groups identified: • Researcher • Red meat industry company • Industry association or employee representative • Research and Development Corporation / industry service organisation as employee/consultant • Government regulator/policy role • Supplier of goods or services to the industry • Customer/ consumer of red meat products • Entrepreneur, funder of research/development • Other (specify)
	Competence of actors	Lack of capability to learn rapidly and effectively due to lack of flexibility, learning potential or resources (Klein Woolthuis, Lankhuizen & Gilsing 2005) Actors may lack competence, capacity to learn or utilise available resources; to identify and articulate their needs; and develop vision and strategies- transition problems (Wieczorek & Hekkert 2012) Firm capabilities: leadership & strategy, culture & systems, learning organisation (Pitt & Nelle 2008)	Was an actor involved in the project? When the actor was/ was not involved • they contributed positively towards the objectives of the project • they neither contributed positively nor negatively to the objectives of the project • they made a negative contribution to the project
	Institutions	Hard institutions such as technical standards, laws, risk management rules, legal system relating to contracts, employment etc. Soft institutions of political culture and social	Existing regulations (or absence of regulations) did not constrain the project Government/regulator general policies (or absence of

Theory	Element	Explanatory material	Survey instrument statements
		values which shape public policy (Klein Woolthuis, Lankhuizen & Gilsing 2005) Specific institutions may be absent, problem with their capacity/quality. Stringent institutional problems may result in the so-called appropriability trap and favour incumbents. Weak institutional problems may hinder innovation, for instance by insufficiently supporting new technologies or developments (Wieczorek & Hekkert 2012) Legal & regulatory framework, industrial relations, rules around R&D, patterns of appropriation (Pitt & Nelle 2008)	policies) did not constrain the project Prevailing rules about what was acceptable did not constrain the project It was easy to understand what was acceptable It was easy to understand what was important, or needed to be achieved There were no difficulties due to industrial/employment practices or issues of industry / regulators It was easy to fit with the prevailing culture (norms, conventions)
	Interaction	Links interactions and cooperative relationships. Both weak (too little) and strong (too much interaction leading to insular groups and myopic thinking) (Klein Woolthuis, Lankhuizen & Gilsing 2005) Missing interactions because of cognitive distance between actors, differing objectives, assumptions, capacities or lack of trust. Quality related - strong network problems - caused by myopia, over strong involvement of incumbent actors, lack of weak ties, dependence on dominating partners due to asset specificity (Wieczorek & Hekkert 2012) Industry-science linkages, co-innovation long value chains, collaboration between firms, open innovation at sector level, shared vision of innovation (Pitt & Nelle 2008)	The different backgrounds and expertise of those involved contributed to achievement Those involved had common objectives or desires a common understanding between those involved was gained Trust was developed between those involved a dominant person/group or a few dominant people/groups contributed to achievement Consensus among one or more groups contributed to achievement Involvement from persons/groups external to the project contributed to achievement
	Infrastructure	Communications and energy (internet, telephone, power) and science-technology infrastructure (scientific knowledge and skills, testing facilities, patents, training, education) (Klein Woolthuis, Lankhuizen & Gilsing 2005) Specific types of infrastructure may be absent or inadequate or	Communication infrastructure (eg phone, email) was not a constraint Information technology (IT) was not a constraint Transport infrastructure was not a constraint storage / warehouse infrastructure was not a constraint

Theory	Element	Explanatory material	Survey instrument statements
		malfunctioning (Wieczorek & Hekkert 2012) Infrastructure failure: ICT, roads, railroads, telecommunications, science &technology, pool of qualified labour, education & training, knowledge dissemination, finance for innovation, physical infrastructure (Pitt & Nelle 2008)	Power availability was not a constraint Water availability was not a constraint The availability of equipment or technologies was not a constraint
	Market	Market factors include market demand, market structures (power exerted by existing actors and barriers to entry of an innovation due to cost) and externalities such as the effect of value chains, delay between investment and benefit, and the geographic location of costs and benefits (Klein Woolthuis 2010) Of particular importance in the context of innovation is market failure leading to under-investment in research. A fully competitive, decentralized market system will provide a sub-optimal level of investment in knowledge development as a consequence of the public good character of certain types of knowledge, of potential knowledge spill-over effects, and of the short time horizon applied by market actors in their investment decisions(Arrow 1962)	The demand by customers for a solution to the problem being addressed in the project was clear The size of the market for products/technology produced as a result of this research justifies the project The results of this project are able to be applied easily by a large number of companies The benefits outweigh the costs of applying the solution proposed by the project The effort in applying the results of the project is small compared to the certain benefits The project provided enough information to allow the results to be applied without significant additional expense
Functional	Entrepreneurial activities	Turning the potential of new knowledge, networks, and markets into concrete actions to generate - and take advantage of - new business opportunities (Hekkert et al. 2007) Investigation of new technologies and applications in an attempt to overcome the uncertainties that exist within a TIS (Bergek et al. 2008) Are there enough entrepreneurs? What is the quality of entrepreneurship?	Researchers discussed ideas with potential users potential users were seeking information about what the project was developing There were significant interactions between the researchers and potential users Suggestions were collected from potential users potential users and researchers worked together on the project There was discussion about how the results of the research could be used

Theory	Element	Explanatory material	Survey instrument statements
		What types of business are involved? What are the products? To what extent do entrepreneurs experiment? What variety of technological options are available? Are any entrepreneurs leaving the system? (Wieczorek & Hekkert 2012) Facilitate experimentation and learning - entrepreneurial experimentation, generating variety, social learning (Cagnin, Amanatidou & Keenan 2012)	
	Knowledge development	R&D and knowledge development are prerequisites with the innovation system - 'learning by searching' and 'learning by doing' (Hekkert et al. 2007) The knowledge base, its evolution, and how knowledge is diffused and combined in the system (Bergek et al. 2010) What is the knowledge base in terms of quality and quantity In the knowledge basic or applied Are there many projects research patents and articles? Is there a leading international position trigger programmes, many cited patents Which actors are particularly active Who finances the knowledge development Does the technology receive attention in national research and technology programs Are there enough knowledge users (Wieczorek & Hekkert 2012) Nurture knowledge development - research and development, knowledge of production design and markets (Cagnin, Amanatidou & Keenan 2012)	Knowledge was developed by the research The knowledge developed was sufficient for the project The knowledge developed was useful for the project Existing knowledge was refined/defined more precisely through the research Existing knowledge was applied to a new situation The way to apply existing knowledge was defined or refined
	Knowledge	Knowledge diffusion through networks - exchange of	New knowledge was published in scientific journals or

Theory	Element	Explanatory material	Survey instrument statements
	dissemination	information, especially between R&D and government competitors and market (Hekkert et al. 2007) Are there strong partnerships Between whom Is the knowledge development demand-driven Is there space for knowledge dissemination Is there strong competition Does the knowledge correspond with the needs of the innovation system Have any licenses been issued (Wieczorek & Hekkert 2012) Promote knowledge diffusion - mediated through networks, supply chains, standards (Cagnin, Amanatidou & Keenan 2012)	presented at conferences New knowledge was published in a form suitable for the potential users New knowledge developed or applied was presented to potential users There was consultation between groups or individual researchers and potential users of the new knowledge There was a demand by potential users for this research before the work commenced Interest was being shown by companies, suppliers, regulators or others in this research/technology Other people or groups were known to be interested in this research/technology
	Guidance of the search	Choices are made from various technological options for further investment, involving industry, government, markets. (Hekkert et al. 2007) Influence on the direction of search - the incentive and/or pressures for organisation to choose to enter the TIS and mechanisms having influence of the search within the TIS (Bergek et al. 2008) Guide direction of the search and selection - guiding actors to select options for investment through visions, expectations, regulations, policy, activities of lead users (Cagnin, Amanatidou & Keenan 2012)	Consultation occurred between relevant groups before the work commenced Consultation occurred with relevant groups or individuals during the research stage Consultation occurred with relevant groups or individuals following the research stage Relevant groups were involved in developing a vision for the potential outcomes of the project Regulations or policy development helped to provide direction to the project The requirements or expectations of customers were considered
	Market formation	Regulation and formation of markets that will allow new developing technologies to continue to develop (Hekkert et al. 2007) The development of a market through capability to, and actual articulation of demand, price/performance, reduction of	Existing regulation/guidelines/policy helped to develop a clear vision for the project The potential to change or respond to regulation/ guidelines/ policy contributed to clear vision for the project There was a clear demand / need / opportunity for the

Theory	Element	Explanatory material	Survey instrument statements
		uncertainties (Bergek et al. 2008) What does the market look like What is its size (niche/developed) Who are the users (current and potential Who takes the lead (public/private parties) Are there institutional incentives/barriers to market formation Must a new market be created or an existing one be opened up (Wieczorek & Hekkert 2012) Promote market formation - create spaces through policies, standards or regulations that nurture demand for innovations. (Cagnin, Amanatidou & Keenan 2012)	application of this research/technology This project was expected to meet a need This project was expected to reduce uncertainties in product qualities, process, or regulatory status
	Resources mobilisation	Supply of resources, both financial and human capital for innovation (Hekkert et al. 2007) The ability of the TIS to provide competence/human capital, financial capital and complementary products, service and network infrastructure (Bergek et al. 2008) Are there sufficient financial resources for system development Do they correspond with the system's needs What are they mainly used for (research/application/pilot projects etc.) Is there sufficient risk capital Is there adequate public funding Can companies easily access the resources (Wieczorek & Hekkert 2012) Develop and mobilise resources - human resources, capital, infrastructure (Cagnin, Amanatidou & Keenan 2012)	The funding available was sufficient The necessary expertise was available The available expertise was utilised Any necessary support (technological infrastructure) was available Any products or services needed for the project were available
	Creation of legitimacy	Counteract resistance to change - becoming part of an incumbent regime or overthrowing it; development of advocacy	The idea of the project was presented to relevant groups

Theory	Element	Explanatory material	Survey instrument statements
		coalitions for processes of change (Hekkert et al. 2007) Social acceptance by relevant actors. Development of positive externalities - entry of new firms may resolve uncertainties, about technologies and markets, may legitimate the TIS either directly or through strengthening the power of advocacy coalitions and may allow new combinations to arise (Bergek et al. 2008) Is investment in the technology seen as a legitimate decision Is there much resistance to change Where is resistance coming from How does this resistance manifest itself What is the lobbying power of the actors in the system Is coalition forming occurring (Wieczorek & Hekkert 2012)	The idea of the project was considered by relevant groups The idea of the project was accepted by relevant groups Alignment between the idea of the project and current regulations or policy was considered Alignment between the idea of the project and anticipated or possible changes to regulation or policy was considered

3.3.2.4 Developing the survey instrument

The survey instrument consists of:

- description of the project
- determination of the actor being represented by the respondent
- assessment of whether some type of innovation occurred
- the status of elements of each theory.

Since innovation systems theory defines networks of actors, it is not reasonable to think that every actor will know about every aspect of a project. The questions allowed for a response that 'I am not in a position to know' for many items, which should have reduced the likelihood of mistaken responses. Additionally, the number of questions that required a response was minimised.

The survey questions were developed in consultation with the supervisory team and local experts. It was pretested, by having typical respondents, not associated with the research, work through the questions and discuss their thoughts and reactions as they do so (cognitive interviewing (Groves et al. 2009)). After pretesting the instrument was pilot tested (Groves et al. 2009) in its on-line format with a number of respondents representing different actors on a project not associated with the subject of the research.

An interval scale was used to measure responses to questions (Hair et al. 2014). A Likert scale (strongly disagree - strongly agree) can be considered to be an interval (metric) scale if the adjacent points are an equal distance apart, which is not the case when asking for qualitative responses. The number of points on the scale must also be considered. Hair et al. (2014) says that even an ordinal (non-metric) scale can be treated as a continuous variable if there are four points or more. Groves et al (2009) suggest the use of five or seven labelled scale points when asking about attitudes. A five point scale is often the default and avoids providing more points than can be reliably be discriminated, but not providing so few that there is little variance in the response. A seven point scale may better conform to the definition of an interval scale and provide opportunity for variance in responses to be expressed (undesirable for most responses to be closely clustered).

Several questions were used in an attempt to measure the presence/effect each of the factors described by the innovation system theories; each element of the approach is a construct in the measurement system. Hair at al. (2014) recommends at least three and preferably four indicators (items) per construct.

3.3.2.5 Administering the survey

The participants were selected based on one of the following:

- MLA records of involvement in the project
- nominated by researcher/contractor as being involved in the project
- recommendations from previous respondents.

The structural theory suggests the importance of actors, so all actors were represented in the survey. Respondents were asked to identify the actor group to which they belonged during the conduct of the project. Also, since information was being sought more than opinion, the sample favoured those who were believed to have most knowledge of the project. The response rate is probably not a critical factor in determining the validity of the data collated at the project level.

The instrument was administered to the identified participants in each project, individually, in a mail (paper/email) or web-based format. SurveyMonkey (https://www.surveymonkey.com/) was used to present the survey to on-line respondents.

To maximise the response rate, the following tactics were employed:

- initial letter invitation
- sending the survey instrument in the preferred format at an agreed rate (some potential respondents will be asked to complete the survey instrument for multiple projects)
- following up twice with reminders.

3.3.2.6 Managing survey data

Multiple responses were obtained for each project that were collated according to the project (unit of observation). Additionally, multiple items (indicators) were used to contribute to the measurement of each innovation system element (construct). A single metric for each project's innovation and innovation system elements was produced by combining all the responses for all the items.

Data were managed by exporting data from SurveyMonkey, storing and manipulating them in Microsoft Excel 2010.

3.3.3 Analytical method: fuzzy-set Qualitative Comparative Analysis

Just as the data collection method needs to be congruent with the chosen epistemological position, Woodside (2016) argues that the analytical tools used need to match theory. The theoretical as well as practical reasons for choosing an analytical method are considered before describing the chosen method.

3.3.3.1 Potential for quantitative analysis

Quantitative analysis using multivariate methods, namely multiple regression analysis and logistic regression are commonly used for determining the relationship between multiple independent variables and a dependent variable. Multiple regression is suitable when there is a metric dependent variable, and logistic regression when the dependent measure exists in only two states (Hair et al. 2014). The measure of innovation may be calculated as a variable (Likert scale for agreement that innovation did occur). Factor analysis could be used to determine the nature of the measurement system (indicators (questions) leading to constructs (system elements) and structural equation modelling may be used to determine the relationships between the constructs and the dependent variable (innovation) (Schumacker & Lomax 2010).

Woodside (2013, 2014, 2016) argues against utilising regression approaches because they model net effects and, ignore the possibility that the effect of a factor may be different when at a low or a high level. He also argues that if theory is based on cases, rather than on the behaviour of two (or multiple) variables within a system, then it is inappropriate to use regression or structural equation modeling with the data. Furthermore, there are dangers in the application of regression analysis (Armstrong 2012).

In all of these techniques critical questions are how statistical significance is determined and the statistical power that can be achieved from the analysis (Hair et al. 2014). Considering the number of independent variables (5-7 for each theory) and the number of cases (41), there may be just sufficient data providing that sufficient data is collected on each case to give a precise estimate of the each parameter and the variation in the data from case to case is relatively large. Logistic regression requires even larger sample sizes to obtain the same statistical power as multiple regression (Hair et al. 2014).

3.3.3.2 Potential for qualitative analysis

Qualitative methods encompass a huge range of techniques (Denzin & Lincoln 2005), few of which would be acceptable, within the chosen ontological frame, for testing theory or providing evidence-based guidelines for practice, however QCA would be suitable.

Woodside (2013, 2014, 2016) argues in favour of configurational testing when working with cases, as being consistent with case study method's epistemological foundations. He also points out the advantages of configurational analyses to deal with multiple combinations of antecedent conditions all able to lead to the same outcome, of models that predict different outcomes from high and low levels of an antecedent condition, and the cause of the absence not being the obverse of the cause of the presence of an outcome.

QCA is a configurational method based on set theory and developed over the past 25 years in three forms: crisp sets, fuzzy sets and also a form able to be used with multiple-category conditions (Rihoux & Marx 2013a). Over 300 peer-reviewed journal articles have made use of QCA methods (Rihoux et al. 2013) particularly in sociology and political science. The method has become more acceptable in business journals (Rihoux et al. 2013); *Journal of Business Research* published eight articles using QCA between 1995 and 2011. Articles using QCA have also appeared in *Research Policy* (Gilbert & Campbell 2015; Meuer, Rupietta & Backes-Gellner 2015), the flagship journal of innovation studies (Godin 2012). QCA arises from the case study tradition in which there is a desire to analyse the results of multiple case studies (including small numbers of cases) and seeks to find the least complex set of variables causally related to the outcome, while acknowledging the possibility that multiple paths may lead to the same outcome (Rihoux 2013). An example of the set-theoretic Boolean logic employed in QCA is that the analysis seeks both necessary and sufficient causal conditions to explain the outcome (Ragin 2006). The article by Fiss (2011) provides an example of the use of factor analysis and fsQCA to analyse business data and produce theories of causal processes.

3.3.3.3 Fuzzy-set Qualitative Comparative Analysis

Two texts provide instruction on the theory and application of QCA methods (Rihoux & Ragin 2009; Schneider & Wagemann 2012). Computer software is available to assist in the computational aspects of QCA (Ragin & Davey 2014), though analysis remains essentially qualitative, from the case study orientation of data collection, to the interpretation of analytical outputs.

QCA is based on set theory and the relation of sets representing the inputs or causes (QCA terminology is 'conditions') with the set representing the output or result (QCA terminology is 'outcome'). Combinations of conditions can lead to an outcome, using the Boolean operators, 'and', 'or', and 'not'.

In the case of fuzzy-set QCA (fsQCA), the data used as conditions and outcomes are variables, and have a degree of set membership, rather than being completely within or outside a set. The degree of set membership, on a scale of 0 (completely without) to 1 (completely within) the set is determined using a calibration procedure in which data are assigned a set membership score based on their relation to three values, those representing: set membership (1.0), set non-membership (0.0), and the point of indifference between membership and non-membership (0.5).

Two relations between a condition set (which may be composed of the union and intersection of several conditions) and an outcome set may exist. The outcome may be a subset of the condition set, that is, that the condition set is always present when the outcome occurs; the condition set is said to be necessary for occurrence of the outcome. On the other hand, the condition set may be a subset of the outcome set, that is, that the outcome always occurs when the condition set is present; these condition sets are said to be sufficient to explain the outcome. QCA provides tests for necessity and sufficiency of the condition for the outcome.

The goodness of fit parameters for both necessity and sufficiency are consistency and coverage. Consistency measures the relative frequency with which the condition/s are associated with the outcome; that is the degree to which the solution terms and the solution as a whole are subsets of the outcome. Coverage measures the proportion of the outcome that is explained by the condition; that is how much of the outcome is explained by each solution terms and the solution as a whole. In the case of necessity, a third parameter, relevance, is used to indicate the extent to which the condition set is larger than the outcome set.

Necessary conditions are identified through the application of a formula to the data. The goodness of fit parameters can be calculated in a spreadsheet. The determination of sufficiency, and the sets of conditions that may be sufficient for an outcome are determined through the construction and minimization of a truth table, most conveniently through the application of software. The truth table identifies cases with similar condition sets and determines the consistency of the outcomes of those cases; only condition sets with consistent outcomes are utilised in the minimisation process. Minimisation determines a minimal number of condition sets (unions and intersections of sets of conditions (for example, A), and negated conditions (for example, NOT A) able to explain the outcome. Three solutions may be determined by the minimisation process: the complex, parsimonious and intermediate solutions. The complex solution uses only the available data, the parsimonious solution uses the logical remainders (the combinations of conditions for which no cases were identified) to determine the simplest solution, and the intermediate solution uses only those logical remainders that fit with theory, in the minimization process.

We determined the complex solution because no assumptions needed to be made about logical remainders. Baugartner and Thiem (2015) have identified problems with the fs/QCA software used, which is more likely with intermediate solutions. The problem identified by Baumgartner and Thiem only rarely arose during this study, and could be avoided.

3.3.4 Other analytical methods

In addition to the main analytical method of fsQCA, other methods were utilised. Woodside (pers. comm.) encourages the use of multiple, appropriate methods to construct and test theory, citing his own (Woodside, Schpektor & Xia 2013) and significant work of others (Fiss 2011; Ordanini, Parasuraman & Rubera 2014) in support of his view. Opportunities to confirm, and extend the findings of fsQCA were taken when appropriate.

3.3.4.1 Relative risk

Relative risk is a measure of the association between exposure to a particular factor and the likelihood (risk) of a particular outcome (Everitt 1995) and used in medical statistics to express, for example, how likely people are to succumb to a disease if exposed to a certain dose of a pathogenic microorganism. The measure was used comparing the association of low membership of the outcome set, when a condition also had low membership of the condition set. The formula used (based on Everitt (1995)) was

$$\text{relative risk of low membership of the innovation set}$$
$$= \frac{\text{rate of low innovation set membership among cases with low membership of the condition set}}{\text{rate of low innovation set membership among cases with high membership of the condition set}}$$

Statistical significance (α=0.05) to the relative risk calculation was determined using Fisher's Exact (two-sided) Test which is appropriate for the small number of cases represented by some combinations of condition and outcome. Dr David Jordan kindly calculated relative risk and statistical significance using Stata SE (version 14).

3.3.4.2 Equality of means

The survey instrument asked respondents whether each potential actor was involved in the project. Further, respondents were asked whether that involvement, or lack of involvement, had a beneficial or detrimental effect on the project. Mean involvement and effectiveness scores were calculated for each actor. A statistical test was applied to determine whether the mean involvement and effectiveness scores were significantly different for cases in which innovation set membership was low or high. A two sided t-test assuming unequal variances was applied using Microsoft Excel.

3.3.4.3 Linear regression

When considering the measurement system and the relationship of the survey instrument response (indicator) to the condition it helped form, it was desirable to quickly measure the relationship. Linear regression between calibrated condition indexes and calibrated single indicators was performed using Microsoft Excel. The slope of the line (m) and the y intercept (b) were calculated. A multiple graph showing linear regression between all indexes and their respective conditions was kindly produced in r software by Dr Andreas Kiermeier.

3.3.4.4 Network Analysis

Network analysis can be a valuable tool to assist in understanding the operation of innovation systems (Coleman, Katz & Menzel 1957; Hartwich & Negro 2010; Musiolik, Jörg & Markard 2011; Wood et al. 2014) and well-developed methods for social network analysis are available (Knoke & Yang 2008; Scott 2000). The data collected through the survey instrument were not suitable for traditional network analysis. However, the involvement and effectiveness of actors in the innovation system, as judged by each of the other actors could be depicted in the form of a network. The actors were represented by circles (nodes), the size of which was related to their perceived involvement by all of the respondents, and the lines (edges) joining them represented the effectiveness as perceived by each of the other actors.

3.3.5 Meeting ethical expectations

There is a societal expectation that research will be performed in an ethical manner. The definitive documents for Australian researchers are the *Australian Code for the Responsible Conduct of Research* (National Health and Medical Research Council, Australian Research Council & Universities Australia 2007) and the *National Statement on Ethical Conduct in Human Research* (The National Health and Medical Research Council, the Australian Research Council & the Australian Vice-Chancellors' Committee 2007 - update 2013). Some specific issues raised in this research are considered and the approach taken to managing the issues are described.

3.3.5.1 Ethical considerations

Those being invited to participate in the survey will have had some involvement or knowledge of food safety research projects conducted through MLA. Projects to be included in the research were first selected and then participants were identified as having some knowledge of, or involvement in, the project.

The student conducting this research is also the manager of these projects for MLA and participants were known to the researcher. The relationship between the participants and the researcher may include one or more of:

- MLA colleague

- employee of an organisation contracted to conduct research for MLA
- consultant engaged to provide services to MLA
- student or former student of a University contracted by MLA to conduct research
- government employee with whom the MLA manager has had contact during the conduct of their employment
- employee of a meat industry company or associated company or industry representative organisation
- someone suggested by one of the foregoing people.

None of the participants are, or were, subordinate employees of the researcher or in substantially dependent relationships with the MLA manager. However, many of the relationships would be judged to be unequal in terms of power. All of those who were involved or have knowledge of the project will have done so through their professional roles.

The *National Statement on Ethical Conduct in Human Research* (4.3.1) says:

> Being in a dependent or unequal relationship may influence a person's decision to participate in research. While this influence does not necessarily invalidate the decision, it always constitutes a reason to pay particular attention to the process through which consent is negotiated.

The ethical issues that required particular attention were:

- the privacy of those participating or involved in MLA projects
- the relationship between the potential respondents and the researcher, because of the researcher's joint role as manager of the MLA food safety program
- the anonymity of respondents.

3.3.5.2 Actions taken to meet ethical expectations

Participants were recruited by direct email process conducted by an MLA staff member other than the researcher, a requirement of *The Privacy Act 1988*, to potential participants identified through the selection process. They were provided with a copy of the Information Sheet prepared by the researchers and were asked to respond to the MLA staff member that they were willing to have their details (name, email address, telephone number) provided to the researcher and to participate in the study. They were also asked in what form they would prefer to receive the survey instrument. Those not responding within one week were followed up by further email by the MLA staff member. This 'screening' process allowed participants to decide whether they wish to consider participation in a non-coercive way. The planned recruitment for the survey provided for 167 people being invited to complete the survey instrument 427 times (average of 2.6 per person; four people were be invited to complete the survey instrument 10 or more times, over a period of a few weeks (negotiable)). Any additional potential participant identified through the survey process was contacted directly by the researcher and recruited following the same process of gaining consent. This process of recruitment, gained agreement from 121 people to complete the survey instrument 312 times.

The Information Sheet prepared by the research team was distributed again by the researcher when sending an introductory email during the survey period. When the survey instruments were distributed, usually by email, requesting an online response, the respondents were reminded of the Information Sheet, and provided with contact details, should they wish to raise any ethical concerns.

The data being collected through the on-line method strictly met the definition of non-identifiable data, but the specific relationship of the survey respondents and the researcher make the data partially identifiable. Multiple participants for each project completed the survey instrument. Even if a respondent completed several surveys, their responses were not linked in any way, because each project had its own survey in the survey software system. It was not possible to identify a respondent by the combination of surveys completed. By the end of data collection, 100 respondents provided 239 responses and over 92% provided substantially complete data.

If participants chose to respond using the online survey instrument then the settings of the survey software were set to send reminder emails only to non-responders without linking the responder to survey instruments already completed. The responses did not provide any identifying information beyond the stakeholder group to which the respondent belonged. The records of potential respondents were not maintained with the survey responses, rendering these data unidentifiable. If a respondent chose to complete the survey by mail or by telephone then their responses were identifiable to the researcher, but once the data were entered into the survey software, they become as identifiable as responses entered online.

It was important for the validity of the research that the identity of the projects (not respondent identities) were known to the researcher. Firstly, the survey responses needed to be understood in the context of the circumstances of the particular project. The QCA case study method benefits from "dialogue with the cases" (Rihoux & Ragin 2009, p.48). Secondly, if further qualitative data collection (for example, semi-structured interview) were required to fully answer the research questions, then projects should be selected based identification of the cases.

The opinions being sought in the survey instrument were derived from experiences and events of a project that occurred in the past and in the course of respondents' professional duties, and were not opinions about performance or management of the manager, the manager's employer (the funding body) or the project itself. No significant risks from the researcher/s identifying the respondents was expected, though the likelihood of this occurring was minimal.

The confidentiality and anonymity of the participants was maintained.

3.3.5.3 Institutional approval

The Tasmania Social Sciences Human Research Ethics Committee approved an application to carry out the research on 27 October 2014 (Reference H0014496).

4

Testing Innovation Systems as theory[6]

4.1 Introduction

Innovation systems thinking is becoming increasingly influential (Manjón & Merino 2012). Innovation systems attempt to explore the complexity of innovation processes, and seek to understand the necessary environments and interactions for successful innovation. Scholars propose innovation system as conceptual frameworks and attempt to maintain conceptual ambiguity to encompass all important factors in innovation (Edquist 1997). Innovation system proponents judge innovation system approaches as useful without explicitly stating a theoretical position or rigorously evaluating the claims to successful intervention. In particular, many authors use one of two theoretical models to explore innovation system failure (Bergek et al. 2008; Klein Woolthuis, Lankhuizen & Gilsing 2005). Scholars use these frameworks, conceptual models, or approaches for analysis, diagnosis, and policy development; however, no studies test those models' ability to explain innovation.

This research tests two innovation system failure approaches as theoretical models on innovation, using QCA (Rihoux et al. 2013). QCA is consistent with the case-study tradition and provides for cross-case analysis with logical rigor (Berg-Schlosser et al. 2009; Yin 2009). QCA can identify conditions causally related to an outcome, while acknowledging the possibility that multiple paths

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may lead to that outcome (Rihoux 2013). QCA allows the statement and testing of theory using set theory. Woodside (2013) points out the value of using QCA for building and testing theory, the generation, and consideration of multiple combinations of conditions on the outcome, and value of considering the individual case. The application of case-study methodology is consistent with the empirical approach of innovation system scholars.

This study employs set theoretic methods (QCA) to define and test theories of innovation system failure. In QCA terms, the specific question is whether all the conditions the theories propose for the outcome of innovation system performance are necessary and sufficient. This study is the first study that formally states innovation system performance frameworks as theories and that tests those theories through multiple case studies.

4.2 Theory

Innovation systems thinking first appears in the 1980s as an attempt to "explain—and perhaps influence—the processes of innovation" (Edquist 1997, p. 2). At that moment, scholars see the activities occurring within innovation systems as broadly aiming at the creation, diffusion, and exploitation of knowledge and ideas. Yet an innovation system extends beyond research activities to organizational competence within firms, capacity for change in organizations, services and institutions therefore maximizing innovation outcomes (Edquist 2005).

The above concepts of innovation systems describe conditions that may, in some combination, lead to successful innovation outcomes. This work compares theories of failure proposed for sectoral and technological systems of innovation. SIS apply to a particular product or service field, whereas TIS consider technological innovation free of other interference or limitations.

SIS focus is on firms in an innovation environment that has product or service boundaries. Scholars describe SIS models “composed of a set of new and established products for specific uses, and a set of agents carrying out activities and market and non-market interactions for the creation, production and sale of those products” (Malerba 2004, p. 16). SIS are a flexible, holistic and interdisciplinary approach to understanding innovation of products and services within an environment that multiple actors and institutions influence (Edquist 2005; Klein Woolthuis, Lankhuizen & Gilsing 2005).

A TIS is a “network of agents interacting in the economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion, and utilization of technology” (Carlsson & Stankiewicz 1991, p. 94). A TIS contains all the components necessary to influence the innovation process for a particular technology (Bergek et al. 2008) and analysis may proceed from consideration of customers, products and/or technologies (Carlsson et al. 2002).

Sectoral and technological innovation system literatures offer the possibility of understanding how and why investment may fail to lead to innovation. The innovation system literature rejects market failure as the sole reason for failure of innovation. Instead, studies consider the concept of innovation system failure to result from imperfections in elements of the innovation system (Klein Woolthuis, Lankhuizen & Gilsing 2005). In QCA terms, research defines a number of conditions resulting in innovation system performance outcome. These conditions may be in a state of imperfection or failure, and may thus prevent innovation system performance, making innovation more difficult or unlikely.

Within the SIS literature, a seminal paper on diagnosis of innovation system problems is that of Klein Woolthuis et al. (2005), whereas within the TIS literature, Bergek et al. (2008) propose an approach to the understanding innovation system functions. Neither study claims to develop or propose theory; rather these studies claim approaches to analysis and policy intervention drawing on empirical studies of their own and others. To trust the ability of these approaches to define the operation of an effective innovation system, a careful analysis of these approaches is necessary to determine the theory they propose, the claims that they make, and the validity of the approaches.

The structural theoretical model (structural theory) of innovation system performance (Klein Woolthuis, Lankhuizen & Gilsing 2005) builds on the assumptions of SIS: that innovation does not occur in isolation, institutions are critical and evolutionary processes play an important role in determining innovation outcomes. The theory acknowledges that imperfections can occur and seeks to define these system imperfections. Five conditions that can affect innovation system performance are institutions, infrastructure, interactions, actor capability (Klein Woolthuis, Lankhuizen & Gilsing 2005) and market factors (Klein Woolthuis 2010). Both Bergek et al. (2008) and Wieczorek and Hekkert (2012) refer to this approach as “structural”. The authors of this structural approach claim the ability to analyze and evaluate innovation systems, to identify the causes of failure, and to provide justification for policy intervention.

The functional theoretical model (functional theory) of innovation system performance (Bergek et al. 2008) builds on the assumptions of TIS and provides another approach to analysis of innovation system performance. Bergek et al. claim that certain processes, or functions, need to occur for innovation system performance. Wieczorek and Hekkert (2012) identify Bergek et al.’s work as a “functional” approach. These authors acknowledge the structural components of the TIS and identify 7 key functions (conditions) operating within TIS: entrepreneurial experimentation, knowledge development, knowledge dissemination, direction of the search, market formation, provision of resources, gaining acceptance. This theory of functional problems aims to help policy makers.

Several scholars use both theoretical models to analyze innovation system performance (Klerkx & Leeuwis 2009), but rigorous testing of the theories is lacking.

The hypothesis under study is that firms must meet all conditions that the structural and functional theories identify to achieve innovation system performance. In set theoretic terms: a case must be within the intersection of sets in which all conditions of both structural and functional theories are operational for innovation system performance to be adequate so that innovation (I) may occur.

Innovation system performance is necessary, but not sufficient for the outcome of innovation (I). In formal notation (Schneider & Wagemann 2012),

$$S_1 * \ldots S_n * F_1 * \ldots F_n \rightarrow ISP \leftarrow I$$

where

$S_1 \ldots S_n$	represents the range of structural theory conditions defined above (n=5)
$F_1 \ldots F_n$	represents the range of functional theory conditions defined above (n=7)
ISP	stands for innovation system performance
I	stands for an innovation outcome
*	means logical 'and'
→	denotes a sufficient condition, as in X implies Y, X is sufficient for Y
←	denotes a necessary condition as in Y implies X, X is necessary for Y

QCA methods permit testing whether all conditions are necessary and sufficient for innovation to occur. Studies can directly measure data on the conditions that the structural and functional theories define; similarly, studies can measure the occurrence of innovation as a case outcome. Scholars can only infer the intermediate outcome of innovation system performance from the occurrence of innovation.

4.3 Method

This study tests the two innovation system theories using multiple case studies within a single sector and technology. The choice of food safety innovation in the Australian red meat sector as the case study is because this sector is at the intersection of a SIS and a TIS, and because of this sector's critical importance in food security. The cases were projects in which managers expected some change (innovation) at the commencement of the project and in which the research phase concluded successfully more than 2 years before the date of data collection. The study used internal records of MLA as a basis to define the projects and the actors involved. Every project meeting the case definition was included in the study.

An on-line survey provided the data. The survey instrument asked questions to determine whether innovation occurred, and the strength of the conditions that the two innovation system theories identified. The study identifies innovation by adapting the OECD (2005) typology to the sectoral and technological domain. The measurement of innovation system conditions in the project used formative scales (Covin & Wales 2011) drawing on responses to several statements using a 7-point Likert scale (except for actor competence which used a 3-point scale) that builds on the definitions and explanations of previous scholars adapted to the domain (Arrow 1962; Bergek et al. 2008; Cagnin, Amanatidou & Keenan 2012; Hekkert et al. 2007; Klein Woolthuis 2010; Klein Woolthuis, Lankhuizen & Gilsing 2005; Pitt & Nelle 2008; van Mierlo et al. 2010; Weber & Rohracher 2012; Wieczorek & Hekkert 2012). The measure that the study uses is the consensus response of all respondents.

The study applies fuzzy set QCA (fsQCA) methods (Rihoux & Ragin 2009; Schneider & Wagemann 2010, 2012) using fsQCA software version 2.5 (Ragin & Davey 2014).

4.4 Results

The survey results form a dataset on 41 projects with 239 responses from 100 respondents (some respondents provide data on more than one project). Over 92% of surveys provide substantially complete data. The program manager at MLA provides additional data for all projects and represents 15.7% of all responses. Less than half (43%) of the responses come from researchers in the projects.

For testing theory, fsQCA is useful for reviewing the relationship between conditions and outcomes, constructing truth tables, suggesting relevant causal configurations through logical minimization, and reporting the consistency and coverage of those configurations.

For each condition in the two theories and the innovation outcome, the study uses a single measure building on responses to several statements using a Likert scale (Table 4.1).

4.4.1 Calibration

Initially, calibration of sets uses estimated parameters because no theoretical or substantive observations to inform the calibration were available (Table 4.2). Adequacy of the calibration procedure consists of noting cases with set membership of 0.5 in either the X or Y parameter and constructing X-Y plots of set membership of innovation (INNOV) against all conditions of each of the S and F theories to observe logically inconsistent results (for example, high membership of all conditions but low membership of innovation). Calibration thresholds undergo modifications to resolve as many of the observed issues in conforming to the theories as possible (Table 4.2). Using re-calibrated data the X-Y plots for both theories conform well to the ideal with no cases at the point of maximum indifference, a few points to the right of the diagonal, and functional theory having one logically inconsistent case (Figure 4.1). This inconsistency is not solvable by recalibration or other procedures applicable across the whole data set (Rihoux & De Meur 2009).

Table 4.1 Data set: measures of outcomes and conditions for all cases

Case	INNOV	ACTOR	INST	INTER	INFRA	MARKET	ENTRE	KNDEV	KNDISS	DIRECT	MKTFOR	RESOURCE	ACCEPT
01	5.00	1.42	5.51	5.44	6.50	5.03	4.44	5.44	5.63	5.62	5.77	5.69	5.75
02	6.60	1.32	4.04	5.82	5.33	5.42	5.71	6.40	6.21	5.95	6.08	5.90	5.90
03	6.83	1.12	4.39	5.44	5.75	5.42	5.61	6.07	6.20	5.72	5.76	5.77	6.00
04	6.75	1.26	5.26	5.42	6.40	5.98	5.19	6.21	6.20	5.92	6.17	6.26	5.80
05	5.88	1.23	4.53	5.57	5.40	5.53	5.81	5.57	5.53	5.64	6.00	6.44	5.51
06	4.40	1.61	5.82	4.86	6.00	4.63	4.46	4.75	4.46	4.53	5.00	5.95	4.81
07	4.00	1.42	5.69	5.41	6.00	4.81	4.58	5.36	5.22	4.63	5.07	5.52	4.33
08	4.00	1.53	5.24	4.93	6.50	4.58	4.22	6.08	4.76	3.75	4.70	5.85	4.13
09	6.17	1.42	5.88	5.64	6.00	5.67	5.42	5.97	5.98	5.46	5.73	6.13	5.60
10	5.50	1.50	5.81	5.20	6.17	4.15	4.99	6.22	5.84	5.27	5.60	5.88	5.70
11	4.50	1.44	4.57	5.19	6.00	5.21	5.79	5.58	5.71	4.75	4.75	6.20	5.15
12	5.00	1.29	5.65	5.64	5.29	5.47	5.84	5.95	5.80	6.06	5.64	6.03	6.08
13	5.33	1.47	5.57	5.21	5.75	5.75	4.96	6.03	4.64	5.25	5.80	5.65	5.45
14	5.14	1.56	5.16	5.18	4.50	5.24	4.56	5.88	5.24	5.48	6.14	6.02	5.84
15	4.00	1.48	5.71	5.32	6.00	4.46	4.29	5.58	4.93	5.00	4.90	5.75	4.95
16	6.00	1.21	5.38	5.71	6.00	5.67	5.28	5.75	6.07	5.78	5.53	6.07	5.73
17	5.40	1.58	5.14	5.71	4.00	5.33	4.87	5.57	5.61	5.37	5.44	5.52	5.55
18	5.00	1.38	6.00	5.37	6.20	5.33	4.30	5.57	5.03	5.30	5.68	5.84	4.80
19	6.50	1.26	4.81	5.20	6.20	5.64	6.13	5.67	6.24	5.92	6.30	5.97	6.03
20	4.86	1.29	5.53	4.79	6.20	5.35	5.14	5.28	5.21	4.58	5.30	6.25	5.30
21	5.56	1.26	5.21	5.60	5.71	5.40	5.59	5.67	5.28	5.47	5.38	6.21	5.80
22	3.50	1.50	5.75	5.10	6.00	3.88	3.89	5.00	5.00	4.44	4.93	5.90	4.53
23	4.00	1.68	4.56	4.96	6.00	4.60	4.98	4.10	4.21	4.47	4.83	5.63	4.52
24	4.57	1.56	5.61	5.83	5.83	5.75	4.62	5.55	5.41	5.51	5.69	5.90	5.53
25	4.86	1.50	5.16	5.55	6.00	4.83	4.30	5.93	5.37	5.01	5.03	6.07	5.00
26	3.57	1.44	5.41	4.44	6.60	3.36	4.55	4.26	4.71	4.63	5.00	5.50	5.07
27	1.00	1.76	4.79	5.30	3.33	4.02	4.33	5.11	3.45	4.89	5.31	5.33	5.30
28	5.78	1.19	5.13	5.39	5.20	5.73	5.79	5.48	5.81	5.90	5.85	5.86	5.93

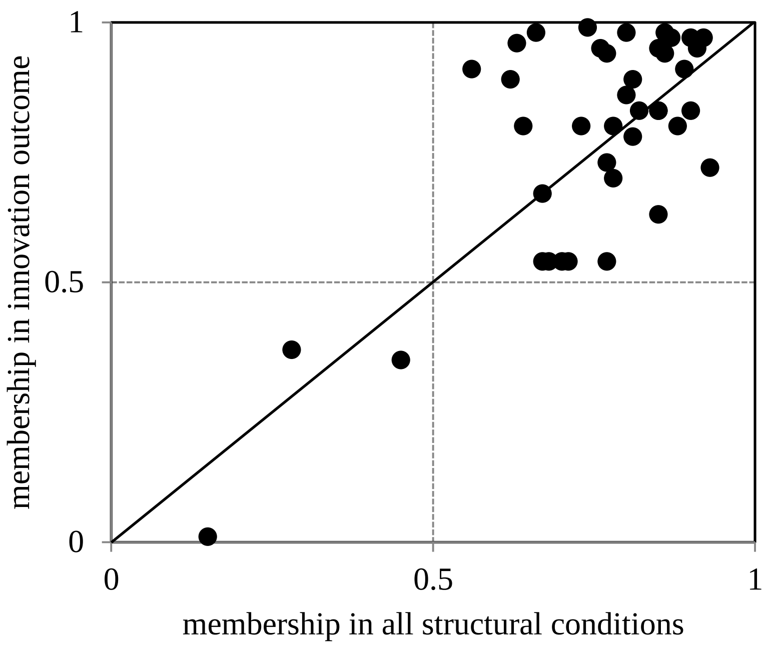
Case	INNOV	ACTOR	INST	INTER	INFRA	MARKET	ENTRE	KNDEV	KNDISS	DIRECT	MKTFOR	RESOURCE	ACCEPT
29	4.00	1.41	6.25	5.46	6.25	4.50	3.58	5.29	4.33	4.44	4.83	5.98	5.13
30	4.29	1.43	5.83	5.43	5.80	5.13	4.75	4.44	4.95	4.93	5.43	5.52	5.21
31	6.20	1.43	3.93	5.42	5.40	5.87	5.77	5.37	5.40	5.43	5.92	5.52	6.14
32	4.89	1.35	5.89	5.52	5.57	5.40	5.04	6.08	5.63	5.69	5.60	6.03	5.65
33	5.91	1.27	5.23	5.47	4.50	5.67	4.96	5.79	5.50	5.64	5.64	5.96	5.46
34	6.29	1.61	6.10	5.60	6.00	6.03	5.37	5.74	5.91	5.57	5.64	6.16	5.76
35	6.44	1.06	5.10	5.75	5.33	6.17	5.25	5.79	6.08	6.06	6.31	6.26	6.10
36	4.89	1.24	5.20	5.00	4.75	5.10	4.68	5.30	5.01	5.32	5.27	5.33	5.35
37	4.80	1.42	5.17	5.48	5.86	4.96	5.38	5.61	5.27	5.12	5.23	5.39	5.33
38	5.00	1.56	4.96	6.14	6.67	5.63	4.96	5.57	5.81	5.58	5.27	6.35	5.35
39	6.00	1.63	5.43	5.07	5.50	5.00	5.42	5.83	5.86	4.54	4.90	5.80	4.90
40	4.60	1.47	6.00	5.11	6.50	5.53	5.22	6.07	5.30	5.92	5.78	5.84	5.48
41	6.22	1.25	5.86	5.79	5.25	5.59	5.33	5.81	6.16	5.91	6.00	5.96	6.07

Table 4.2 Definition of parameters and their fuzzy set calibration

Parameter type	Parameter (abbreviation)	Membership threshold	Point of maximum indifference	Non-membership threshold
Outcome	Innovation (INNOV)	6	4 (3.9 for structural theory, 4.45 for functional theory)	2
Structural condition	Actor competence (ACTOR)	1.5	2	2.5
	Institution (INST)	6	3.5	2
	Interactions (INTER)	6	4.5	2
	Infrastructure (INFRA)	5	4 (3.8 for structural theory)	3
	Markets (MARKET)	6	4.5 (4.0 for structural theory)	2
Functional condition	Entrepreneurial experimentation (ENTRE)	5	4	2
	Knowledge Development (KNDEV)	6	5 (5.1 for functional theory)	3
	Knowledge Dissemination (KNDISS)	6	3.5	2
	Direction of the search (DIRECT)	6	4.5	3
	Market formation (MKTFOR)	6	3.5	2
	Resources (RESOURCE)	5.5	3.5	2
	Acceptance (ACCEPT)	6	4.5	2

Note. The empirically selected threshold for the point of indifference is shown, along with the modified threshold used to recalibrate the data.

a) Structural theory



b) Functional theory

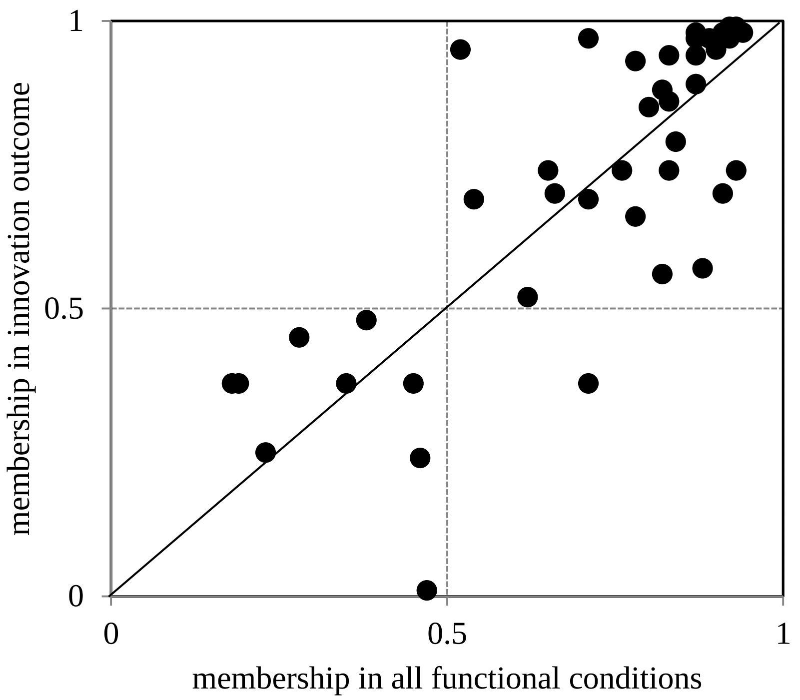


Figure 4.1 X-Y Plots of set membership in the outcome (INNOV) against conditions for Structural and Functional theories, using modified calibration parameters

4.4.2 Necessity

The study tests the proposition that the conditions of each theory are necessary for an innovation outcome, that is, $X_n \leftarrow I$ (Schneider & Wagemann 2012). Both consistency of the data, that is, the extent to which condition X is necessary for the outcome Y, and the coverage of the data, that is, the relation in size between the outcome set and the condition set, are very high (Table 4.3). The relevance of the necessity, that is, how far a set X is not only a superset of Y but also the degree to which X is not much bigger than Y or ~X, is also high. These values indicate, with a high degree of certainty, the necessity of the combined conditions, of each theory, to produce the innovation outcome.

Table 4.3 Measures of goodness of fit for necessity

Theory	Consistency	Coverage	Relevance
S	0.901027	0.940240	0.847303
F	0.904844	0.914266	0.831514

4.4.3 Sufficiency

The next step in the study is the construction of truth tables for each theory (Tables 4.4 and 4.5). Very limited diversity occurs in the data, with a very high proportion of cases having > 0.5 membership of the INNOV set and > 0.5 membership in the set of all conditions. These data do not meet the diversity criterion for quality of a truth table (Rihoux & De Meur 2009) but additional data or recalibration of the data are not available options to address this concern.

Table 4.4 Truth table for Structural theory (without logical remainders)

ACTOR	INST	INTER	INFRA	MARKET	Number of cases	Raw consistency
1	1	1	1	1	38	0.940240
1	1	1	1	0	1	0.932735
1	1	1	0	1	1	0.671053
1	1	0	1	0	1	0.945489

Table 4.5 Truth table for Functional theory (without logical remainders)

ENTRE	KNDEV	KNDISS	DIRECT	MKTFOR	RESOURCE	ACCEPT	Number of cases	Raw consistency
1	1	1	1	1	1	1	32	0.914266
1	0	1	1	1	1	1	3	0.824121
1	1	1	1	1	1	0	1	0.912363
1	1	1	0	1	1	0	1	0.890302
1	1	0	1	1	1	1	1	0.890110
1	0	1	0	1	1	1	1	0.864297
0	1	1	0	1	1	1	1	0.837975
0	0	1	0	1	1	1	1	0.827476

The structural theory truth table reveals that only 3 cases do not have set membership > 0.5 in INNOV and all of these cases have membership of a condition set < 0.5 (INTER, INFRA, MARKET). Thirty-eight cases have membership of > 0.5 in all conditions and > 0.5 membership in INNOV. The functional theory truth table reveals 10 cases with < 0.5 membership in INNOV, and 9 of these 10 cases have membership of < 0.5 in at least one of the condition sets (ENTRE, KNDEV, KNDISS, DIRECT, ACCEPT); the remaining case being a logical contradiction. Thirty-one cases have membership of > 0.5 in the set of all conditions and > 0.5 for INNOV.

Truth table minimization uses two consistency thresholds (Table 4.6): the consistency of the configuration with the highest raw consistency, and one with lower, but still very acceptable consistency. For theory testing, no discarding of cases occurs because of low frequency (i.e., frequency threshold = 1). The computation of the complex solution (Ragin 2009) takes place. The complex solution is appropriate for theory testing because no assumptions occur about the possible outcomes for configurations for which the analysis identifies no cases (logical remainders). In all analyses, the configuration that is most complete has the highest raw and unique coverage. The consistency and coverage of the configurations is high, indicating that, for both the structural theory and the functional theory, the combination of all conditions is sufficient to produce an innovation outcome.

4.4.4 Evaluation of theories in set theoretic terms

Empirically, for structural theory all 3 cases with ≥ 1 condition with a set membership of < 0.5 have < 0.5 membership of the innovation outcome set. All 38 cases having a membership for all conditions of > 0.5 have > 0.5 membership of the innovation outcome set. For functional theory, all 9 cases with ≥ 1 condition with a set membership of < 0.5 have < 0.5 membership of the innovation outcome set. Thirty-one out of 32 cases having a membership for all conditions of > 0.5 had > 0.5 membership of the innovation outcome set. Only the use of functional theory results in a single case that deviates from the expectations.

For both theories, the consistency and the coverage of the causal configurations for explaining the sufficiency and necessity of the conditions for explaining the innovation outcome is very high.

4.5 Discussion and conclusion

The analysis suggests, at least for the kind of innovation that this intersection of a SIS and a TIS represents, that both theories for understanding innovation system performance are acceptable; no falsification exists. With the limitation of lack of diversity in the cases (no cases represent lack of set membership for some conditions) and therefore limited ability to test, no conditions are unnecessary (optional) for an innovation outcome, and without limitation, all conditions are sufficient for an innovation outcome. A recent study of performance in an innovation-driven industry - the Taiwanese biotechnology industry (Huang & Huarng 2015) - also using fsQCA, demonstrates the importance of meeting multiple conditions to achieve success.

Table 4.6 Complex solution to truth table minimization (outcome: innovation)

Theory	Consistency threshold	Causal configuration, coverage and consistency	Raw coverage	Unique coverage	Consistency
structural	0.932735	actor*inst*infra*~market	0.194211	0.000000	0.900433
		actor*inst*inter*infra	0.912543	0.718332	0.908866
		solution coverage: 0.912543			
		solution consistency: 0.902154			
structural	0.940240	actor*inst*inter*infra*market	0.901027	0.901027	0.940240
		solution coverage: 0.901027			
		solution consistency: 0.940240			
functional	0.890110	entre*kndev*kndiss*mktfor*resource*~accept	0.206802	0.006527	0.882698
		entre*kndev*direct*mktfor*resource*accept	0.905531	0.705256	0.913059
		solution coverage: 0.912058			
		solution consistency: 0.903061			
functional	0.914266	entre*kndev*kndiss*direct*mktfor*resource*accept	0.904844	0.904844	0.914266
		solution coverage: 0.904844			
		solution consistency: 0.914266			

The evaluation of goodness of fit measures suggests that the two theories have essentially equivalent explanatory power. From a practical viewpoint, the calibration of INNOV that the study uses for the functional theory identifies 9 cases as having < 0.5 membership of INNOV, 3 that appear in the structural theory and 6 additional ones. The functional theory may therefore be more useful in identifying conditions that need assessment, and possibly management, to increase the likelihood of innovation.

Combining both theories identifies additional conditions to ensure innovation. However, the application of both theories does not identify additional cases of low membership of the innovation set. A correlation may exist between some of the conditions of one theory and those of the other. Given the different perspectives and the suggestion (Bergek et al. 2008) that scholars should consider both sets of conditions, proceeding using both theories would be wise.

This work demonstrates the value of QCA methods in developing theoretical statements that allow testing, guiding methodology for data collection and conducting analysis to test theory. When developing theoretical statements, QCA demands the statement of the theory in definite, logical terms that admit both the presence of conditions leading to an outcome and the causal relationship. The use of set theory notation encourages the use of logical definitions and precise statement, which aids in the development of data collection systems.

QCA methods are suitable for relatively small data sets without sacrificing rigor. In this study, a limited number of cases are available for study after defining the boundaries to the intersection of a sectoral and technological innovation system and controlling other factors. Even after collecting data from as many respondents as possible, a limited quantity of data from representatives of different actors is available. These data limitations do not prevent the analysis using QCA, though limited diversity in the data results in some qualification to the conclusions.

The analysis clearly shows conformity of cases with the theory. Lack of conformity with theory may result in a deeper review of cases, definitions, or theories in a transparent manner. Relativistic quantitative analysis does not address a sense of the absolute in QCA because the arrangement of equations aims at coefficients and p values meeting of acceptable criteria but without the same degree of concern for logic (Woodside 2014).

Structural and functional theories of innovation system performance are equally valid for identifying conditions that lead to innovation system performance outcomes. QCA is a useful technique that aids in the statement and testing of theory.

5

Innovation System problems: Causal configurations of innovation failure[7]

5.1 Introduction

Innovation systems define a framework for exploring the complexity of innovation processes, and seek to understand the necessary environments and actions for successful innovation (Edquist 1997). Two theoretical models, one arising from SIS and the other from TIS approaches, are useful to explore innovation system failure and develop policies in an attempt to overcome that failure (Bergek et al. 2008; Klein Woolthuis, Lankhuizen & Gilsing 2005). Innovation system failure theories (Bergek et al. 2008; Klein Woolthuis 2010; Klein Woolthuis, Lankhuizen & Gilsing 2005) propose that all elements of an innovation system must be present to achieve innovation system performance. The structural theory that arises from SIS thinking seeks to identify system failure in the relationship between the actors in the system and structural elements such as institutions, infrastructure, as well as interactions between actors (Klein Woolthuis 2010; Klein Woolthuis, Lankhuizen & Gilsing 2005). The functional theory arises from TIS thinking and seeks to find problems (weaknesses) in the functions that need to occur within an innovation system such as knowledge development, acceptance of the technology, provision of resources, and entrepreneurial experimentation (Bergek et al. 2008).

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A recent study shows that both structural and functional theories are valid at the project level, explaining the ultimate failure of projects to result in innovation despite success at the research stage (Chapter 4). This study uses fsQCA (Rihoux et al. 2013) to show that all of the conditions of each of these theories are collectively necessary and sufficient for innovation system performance (Chapter 4). However, no understanding exists of whether common patterns of system problems (i.e., weak conditions) occur within an innovation system.

This research uses fsQCA to explore the application of conditions that the structural and functional theories identify as leading to the failure of innovation systems to the failure of successful research to lead to innovation outcomes. FsQCA identifies possibly multiple sets of conditions that may causally relate to an outcome (Rihoux 2013). Analysis of multiple cases of food safety research projects in the Australian red meat industry, situated at the intersection of sectoral and technological innovation systems, allows comparison of the two theories of innovation failure. The application of case-study methodology (Yin 2009) is consistent with the empirical approach of innovation system scholars and QCA analysis (Berg-Schlosser et al. 2009).

This study posits that an innovation system performs in a consistent way from project to project, and therefore, the same condition(s) are likely to be weak in multiple cases and result in the failure to innovate. Cases with a weak conditions (<0.5 fuzzy-set membership) would therefore be significantly more likely to result in lack of innovation system performance and an innovation outcome (<0.5 fuzzy-set membership). If consistently weak conditions that restrict innovation system performance exist, then actors can modify the innovation system to enhance performance. This study also explores the relative utility of the structural theory perspective and the functional theory perspective for understanding innovation system failure.

5.2 Method

The study used data on research projects that MLA conducted (Chapter 4). The cases were projects in which managers expected some change (i.e., innovation) at the commencement of the project and in which the research phase concluded successfully more than two years before the date of data collection. An on-line survey instrument asked questions to determine whether innovation occurred, and the strength of the conditions that the two innovation system theories identified, usually using a 7-point Likert scale. The study measured the innovation outcome using the OECD typology (Organisation for Economic Co-operation and Development & Statistical Office of the European Communities 2005) within the context of the sectoral and technological innovation systems. The study also measures the strength of innovation system conditions drawing on formative constructs and using multiple indicators that the innovation system literature describes.

The study drew on fsQCA methods (Rihoux & Ragin 2009; Schneider & Wagemann 2010, 2012) and used fsQCA software version 2.5 (Ragin & Davey 2014). The data has low diversity for many parameters, including the outcome (Chapter 4), which is undesirable because of the limitation lack of diversity imposes on the comparative ability of the QCA method. After calibrating and adjusting the data to avoid set membership of 0.5, only three cases have < 0.5 set membership in the innovation outcome (INNOV). Changing the calibration parameters of INNOV to a higher point of indifference can result in a higher certainty that innovation occurred and higher diversity in the calibrated data because more cases have INNOV scores less than the point of indifference. In the data, a score of 4 means that the average respondent "neither agrees nor disagrees," whereas a score of 5 means that the average respondent "somewhat agrees" that at least one example of innovation resulted from the project. The selection of different calibration parameters for the point of maximum indifference produced four levels of INNOV certainty from 3.8 to 4.9 (see Table 5.1). Innovation system failure theory (Bergek et al. 2008; Klein Woolthuis, Lankhuizen & Gilsing 2005) and evidence using this dataset (Chapter 4) supports the idea that every condition must be strong to result in innovation system performance and, therefore, innovation outcomes. Consequently, the study adjusted the calibration of the condition's point of maximum indifference, from either structural theory or functional theory, so that for every case with <0.5 membership of the INNOV outcome, at least one condition with <0.5 membership existed. Because the recalibration applies to all cases, the recalibration of several conditions could occur at each adjustment of the outcome.

The process of recalibration of the outcome and the identification and recalibration of the weakest condition ensured that, for each case with < 0.5 set membership of innovation, at least one condition also had < 0.5 set membership. The study determined the configurations of causal conditions for lack of innovation (~INNOV) through generation and minimization of the truth table and the resulting complex solution.

The study can determine the association of conditions with low membership of the innovation set by calculating the relative risk (Everitt 1995) of low set membership of innovation when the membership of the condition set is also low. The study also determined the significance using Fisher's Exact (two-sided) Test. Strata SE (version 14) calculated relative risk and statistical significance[8].

5.3 Results

The survey results from a dataset on 41 projects with 239 responses from 100 respondents (some respondents provide data on multiple projects). The respondents represent the actors involved in the projects, including the project managers, researchers, and the industry firms and their representative bodies.

Recalibration of the innovation outcome to higher levels of certainty (see Table 5.1) results in between 3 and 18 of the 41 cases having set membership of < 0.5 in the INNOV outcome.

Three approaches identify weak conditions that contribute to the failure of innovation system performance (~INNOV). First, at the case level, the study observes the conditions that frequently have the lowest membership of the condition set and recalibrates those conditions. Second, the

[8] Dr. David Jordan and Dr. Andreas Kiermeier provided valuable statistical advice. Dr. Jordan assisted with the computation of relative risk.

study identifies, using fsQCA's logical minimization procedures, weak conditions and configurations of conditions to explain ~INNOV (<0.5 membership of INNOV), and conditions and configurations of conditions with high coverage (i.e., with ability to explain the outcome). Third, the study identifies weak conditions and combinations of conditions that across all cases significantly associate with ~INNOV.

5.3.1 Weak conditions according to the structural theory

Through successive steps of recalibration of INNOV, INTER and INFRA are the conditions that have minimum set membership, therefore the study subjects these conditions to recalibration (Table 5.1). The point of maximum indifference changes only slightly for INFRA, but significantly for INTER when following this procedure.

The configurations for innovation failure are quite similar at each of the four levels of innovation certainty. The analysis identifies MARKET as a weak condition (condition with < 0.5 set membership) at all levels of innovation certainty (see Table 5.2) despite the calibration remaining constant. INTER and INFRA may or may not be part of the configurations, indicating some uncertainty about their contribution to ~INNOV, until the highest level of innovation uncertainty where ~INTER associates with ~INNOV, but with low coverage. The lower raw coverage of the solutions to explain ~INNOV with higher levels of innovation certainty is due to some cases having a contradictory outcome for some condition configurations.

The relative risk of ~INNOV in cases with weak conditions is consistent with the fsQCA (see Table 5.3). ~MARKET significantly increases the probability of ~INNOV at three levels of innovation certainty. ~INTER significantly associates with ~INNOV at only one level of innovation certainty. At the highest level of certainty for innovation, neither condition is significant by itself, but when together, a significant difference in risk of innovation failure between cases having set membership of both conditions and non-set membership of both conditions exists.

Table 5.1 Definition of parameters and their fuzzy set calibration at different levels of certainty of innovation system performance

Parameter type	Parameter (abbreviation)s	Membership threshold	Non-membership threshold	Point of maximum indifference for four levels of certainty of innovation system performance			
				Level 1	Level 2	Level 3	Level 4
Outcome	Innovation (INNOV)	6	2	3.8	4.1	4.6	4.9
	Number of cases with < 0.5 membership			3	8	13	18
Structural condition	Actor competence (ACTOR)	1.5	2.5	2	2	2	2
	Institution (INST)	6	2	3.5	3.5	3.5	3.5
	Interactions (INTER)	6	2	4.5	4.5	5.17	5.63
	Infrastructure (INFRA)	5	3	3.8	3.8	3.9	3.9
	Markets (MARKET)	6	2	4.48	4.48	4.48	4.48
Functional condition	Entrepreneurial experimentation (ENTRE)	5	2	4	4	4	4
	Knowledge Development (KNDEV)	6	3	4.85	4.85	5.6	5.7
	Knowledge Dissemination (KNDISS)	6	2	3.5	3.5	3.5	3.5
	Direction of the search (DIRECT)	6	3	4.5	4.5	4.8	5.7
	Market formation (MKTFOR)	6	2	3.5	3.5	3.5	3.5
	Resources (RESOURCE)	5.5	2	3.5	3.5	3.5	3.5
	Acceptance (ACCEPT)	6	2	4.5	4.5	4.5	4.5

Table 5.2 Complex solutions for ~INNOV using the structural theory

Level of innovation certainty	Configuration of conditions					Raw coverage	Solution coverage	Solution consistency
	ACTOR	INST	INTER	INFRA	MARKET			
1	+	+	0	+	~	0.80	0.86	0.75
	+	+	+	0	~	0.84		
2	+	+	0	+	~	0.72	0.77	0.82
	+	+	+	0	~	0.74		
3	+	+	0	+	~	0.54	0.58	0.86
	+	+	+	0	~	0.53		
4	+	+	~	+	~	0.48	0.48	0.86

+ means that the condition with membership >0.5 included in the solution, ~ means the condition with membership <0.5 included in the solution, 0 means that the condition is indifferent to inclusion in the solution

Table 5.3 The relative risk of ~INNOV outcome if the case has weak set membership of the condition set using structural theory

Level of innovation certainty	Relative Risk of ~INNOV when condition set membership <0.5			
	INTER	INFRA	MARKET	INTER* MARKET
1	20	20	∞*	
2	5.7	5.7	7.2*	
3	3.0*	3.3	3.2*	
4	4.8	2.4	2.1	6.4*

* p < 0.05

5.3.2 Weak conditions according to the functional theory

Through successive steps of recalibration of INNOV, KNDEV and DIRECT are the conditions that have minimum set membership and the study, therefore, subjects these conditions to recalibration (see Table 5.1). The point of maximum indifference changes significantly for both conditions.

The logical minimisation procedure for lack of innovation results in multiple alternate configurations at all levels of innovation certainty (see Table 5.4). Similarities exist in the configurations between one level of certainty and another. Many of the configurations have relatively high coverage, although the solution coverage falls as the level of innovation certainty increases. Five conditions contribute to ~INNOV when they are weak: ENTRE, KNDEV, KNDISS, DIRECT, and ACCEPT. ENTRE and ACCEPT appear in configurations, often in conjunction with other weak conditions, at lower levels of innovation certainty, but become less prominent at high levels of certainty. Weakness in KNDEV, KNDISS and DIRECT affect multiple configurations at all levels of innovation certainty and often in combination with each other. DIRECT and KNDEV are present in configurations one without the other at lower levels of certainty; however, at higher levels of innovation certainty KNDEV is only present in conjunction with DIRECT.

The relative risk of ~INNOV in cases with weak conditions is consistent with the fsQCA (see Table 5.5). KNDEV and DIRECT are frequently statistically significant conditions. KNDEV is more significant at low certainty of innovation and DIRECT is more significant at high levels of certainty. They highly significantly associate with ~INNOV when both are weak. While the relative risk relating to weakness in KNDISS may be as high as KNDEV and DIRECT, this relative risk is not statistically significant, alone or in combination with other conditions.

Table 5.4 Complex solutions for ~INNOV using functional theory

Level of innovation certainty	Configuration of conditions							Raw coverage	Solution coverage	Solution consistency
	ENTRE	KNDEV	KNDISS	DIRECT	MKTFOR	RESOURCE	ACCEPT			
1	+	~	+	0	+	+	+	0.62	0.848	0.72
	+	+	+	0	+	+	~	0.65		
	~	+	+	~	+	+	+	0.45		
	+	+	~	+	+	+	+	0.50		
2	+	~	+	0	+	+	+	0.55	0.78	0.81
	+	+	+	0	+	+	~	0.57		
	~	+	+	~	+	+	+	0.39		
	+	+	~	+	+	+	+	0.41		
3	+	0	+	~	+	+	0	0.62	0.65	0.84
	0	~	+	~	+	+	+	0.53		
	+	~	~	+	+	+	+	0.27		
4	+	0	+	~	+	+	0	0.64	0.67	0.82
	0	~	0	~	+	+	+	0.53		
	+	~	0	~	+	+	+	0.52		

+ means that the condition with membership >0.5 included in the solution, ~ means the condition with membership <0.5 included in the solution, 0 means that the condition is indifferent to inclusion in the solution

Table 5.5 The relative risk of ~INNOV outcome if the case has weak membership of the condition set using functional theory

Level of Innovation certainty	Relative risk of ~INNOV when condition set membership < 0.5							
	ENTRE	KNDEV	KNDISS	DIRECT	ACCEPT	ENTRE * DIRECT	KNDEV * KNDISS	KNDEV * DIRECT
1	9.8	4.6	20	4.6	0	9.2		
2	6.5*	3.1	5.7	9.2*	6.5*	9.2*		
3	3.5	5.8*	3.3	4.9*	3.54		7.7	8.6*
4	2.4	2.7*	2.3	5.0*	2.4			7.5*

* p < 0.5

5.4 Discussion

This study, using a measurement system and fsQCA, provides insights into the relationship between innovation system conditions and innovation system performance, thus contributing to a deeper understanding of innovation systems and the use of QCA in analysis of cause and effect in managed systems.

5.4.1 Innovation Systems

This research contributes to innovation system theory, policy, and practice by demonstrating that recurring weaknesses may exist within an innovation system that affect innovation system performance and, therefore, are amenable to systemic rectification through policy measures or management practices. This research, instead of drawing on descriptive approaches, uses a measurement system that builds on the opinions of actors within the system to provide multiple perspectives on innovation system conditions.

According to construction of the structural theory, to achieve a more certain innovation outcome, interactions between innovation system actors need to be highly effective. Interactions between actors in an innovation system are critically important, with two major caveats: (1) strong interactions can result in a myopic perspective; and (2) weak interactions may contribute to a lack of shared vision and learning (Klein Woolthuis, Lankhuizen & Gilsing 2005). Likewise, the weakness of the market condition is the clear causation of poor innovation system performance across many cases in this study. Although market failure is an issue in food safety improvement (Caswell 1998), innovation system literature not always considers this kind of failure seriously, with some scholars specifically rejecting market failure arguments (Bleda & Del Río 2013). Although the SIS failure model does not initially include market failure (Klein Woolthuis, Lankhuizen & Gilsing 2005), later scholarship leads to the incorporation of market failure into innovation system theory (Klein Woolthuis 2010).

From a functional theory perspective, a larger number of alternate configurations exist leading to lack of innovation system performance in comparison to the structural theory, which has a correspondingly larger number of weak conditions. However, the only conditions consistently implicated on the lack of innovation system performance, either alone or in combination, are DIRECT and KNDEV. The concept of direction, or guidance of the search (Bergek et al. 2008; Hekkert et al. 2007) within an innovation system refers to the incentives and pressures that cause an organisation to become involved and motivate actors to take particular actions within the innovation system. The articulation of expectations among the potential users of a technology and the response of technology providers is a key aspect in providing direction (Budde, Alkemade & Weber 2012; Hekkert et al. 2007). Depending on the situation, guidance of the search may develop from the decisions that independent actors make (Budde, Alkemade & Weber 2012), or from a top-down approach to fit with regulatory, institutional, or cultural norms (Vidican et al. 2012). Knowledge development in an innovation system occurs when actors in the innovation system research, experience, and synthesize new knowledge through social processes (Cagnin, Amanatidou & Keenan 2012; Hekkert et al. 2007; Nonaka & Toyama 2003).

The findings of the study only apply to the intersection of sectoral (i.e., red meat) and technological (i.e., food safety) innovation system from which data comes, and for the period in which the projects are active. However, these projects span a period of over ten years, from which the study can infer a certain constancy of conditions applying to the innovation system. In addition, the findings may provide insight to other innovation systems that require knowledge-intensive innovations that are subject to a high level of regulatory compliance, have public welfare dimensions, and that are largely supported using public or industry funds (Core & Australian Department of Agriculture Fisheries and Forestry 2009; Desmarchelier & Szabo 2008).

This study does not identify the TIS functions that drive innovation system performance. Direction (i.e., guidance) of the search, entrepreneurial activities, and legitimation (i.e., acceptance) are typical drivers of innovation system development (Hekkert et al. 2007) and are significant at different stages of technology development (Suurs & Hekkert 2009; Suurs, Hekkert & Smits 2009). This analysis does not have a temporal component, but rather identifies the functions that are most likely to require attention to facilitate innovation system performance. Only one of these three functions is recurrently weak in this system, but not in all cases. Innovation system actors should pay attention to both the drivers and the most frequently weak conditions of the innovation system to maximise the possibility of successful innovation.

Both the structural theory and the functional theory are capable of predicting innovation system failure. The coverage and consistency parameters for multiple sets of configurations are acceptable. The functional theory identifies more paths for failure to innovate than the structural theory does. Additionally, more conditions in the functional theory contribute to innovation failure than in the structural theory. These findings suggest that the conditions of the structural theory are more consistent over many cases, whereas the conditions of the functional theory are more variable from case to case. The structures are somewhat constant in comparison to the dynamic functions within an innovation system. Policy approaches might effectively manage the weaknesses found using structural theory, whereas management at the project (i.e., case) level might effectively manage the weaknesses from a functional theory perspective.

More importantly, the analysis of an innovation system over multiple cases shows that the same weaknesses occur repeatedly. The causes of a specific innovation system's failure to innovate are not random, and therefore are amenable to policy and managerial interventions to overcome these recurrent weak conditions identifiable through fsQCA.

The measurement system that this study uses predicts innovation system performance. The use of such an instrument may allow the collection of data during the conduct of a project and provide guidance to policy-makers and managers as they seek to maximise the chance of successful innovation.

5.4.2 The application of fsQCA

This investigation uses two methods of analysis: FsQCA and relative risk, thus providing an opportunity for triangulation of results (Woodside, 2016). Calibrating the outcome to four levels of certainty (on the Likert disagree-agree scale) and then recalibrating the conditions to fit with the innovation system theory that failure of outcome associates with failure of at least one condition induces diversity into the data that is not obvious with the standard calibration procedure. The approach also identifies consistent patterns of conditions at differing levels of outcome certainty. The chance of attaching significance to sets of conditions that might be the product of the selection of certain calibration values is lower when using multiple calibration values. This method indicates the magnitude of point of indifference of the condition on the Likert scale necessary to produce a high level of innovation certainty. The method this study uses requires the adjustment of only one condition from either theory, which avoids over-identifying conditions contributing to innovation failure, and probably reduces the solution coverage.

Calculating the relative risk to assess the strength of association between an outcome and a potentially causative factor is a standard statistical technique. The study applies this technique to the risk of innovation failure if a condition is weak rather than strong. The study can determine the size of the potential effect and the statistical significance.

Overall, the two methods of analysis produce largely similar results. Confirming the results of fsQCA using another method provides additional confidence (Woodside, 2016). Knowing the magnitude of the relative risk provides a measure of the importance of the conditions to the innovation outcome. Most analyses do not calculate the relative risk for combinations of conditions unless necessary, whereas the design of fsQCA analysis considers combinations of conditions that contribute to innovation failure.

Referring to the calibrations of the data, particularly the choice of the point of maximum indifference provides an insight into the quantum of a particular condition that is necessary to result in higher levels of certainty of innovation system performance. Of the four conditions frequently weak three require an average response of >5.5 on a 7-point Likert scale to be strong. The conditions of interaction, direction, and knowledge development need to be particularly high to provide a high certainty of innovation.

5.5. Conclusion

This research uses fsQCA to analyse a dataset with little diversity, drawing on standard calibration, and inducing greater diversity that allows the identification of the conditions necessary to achieve high certainty of innovation system performance. The point of indifference for innovation system conditions for weak conditions provides an indicator of the quantum of the condition necessary to ensure innovation system performance.

Furthermore, this research demonstrates an approach to analysing an innovation system to understand the conditions that affect innovation system performance. The analysis of innovation systems over multiple cases shows that the same weaknesses occur repeatedly and are therefore amenable to policy and management action to overcome these weaknesses.

Both the structural and functional theory perspectives are capable of predicting innovation system failure. The conditions that the structural theory identifies are perhaps more consistent across cases than the conditions that the functional theory identifies, which implies that the conditions of each theory may need a different management approach. Influencing structural theory parameters might require policy interventions, whereas functional theory conditions often require managerial action. This study hopefully stimulates additional work in the application of fsQCA on innovation systems and utilising both structural and functional theory perspectives.

6

The root cause of innovation system problems: Formative measures and causal configurations[9]

6.1 Introduction

Innovation systems approaches attempt to provide a holistic understanding of the environment and interactions that are necessary for the occurrence of innovation (Edquist, Charles 1997); these approaches are influential in setting a national innovation policy (Manjón & Merino 2012). Recent research shows two approaches to understanding innovation system performance, from sectoral and technological perspectives, both equally applicable at the project level. This research, using fsQCA, is also useful for developing a causal recipe for innovation system failure (Chapter 5). According to IS theory innovation system performance can occur only when all conditions (in the QCA sense) occur. For example, the sectoral theory describes the conditions of interaction, infrastructure, and institutions, whereas the functional theory describes conditions such as provision of resources, direction of the search, knowledge development, and knowledge dissemination. This study uses fsQCA to identify recurrently weak conditions that the theories specify, in a selected IS, and therefore are likely to affect negatively innovation system performance and the success of innovation projects. Poor innovation system performance can be the result of weakness in conditions from either theory; however, the relationship between both theories' conditions is unclear.

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The literature broadly defines the conditions of an IS (Bergek et al. 2008; Hekkert et al. 2007; Klein Woolthuis 2010; Klein Woolthuis, Lankhuizen & Gilsing 2005). Scholars of IS failure theory tend to combine in categories the many reasons why innovation may fail, sometimes resulting in including combinations of indicators orthogonal to each other within the same condition. Therefore, the identification of weakness in a condition may be insufficient to allow policy or management action to correct the performance of the system because the definition of the conditions is not sufficiently precise.

The measurement model (Figure 6.1) has several formative indicators for each condition. Formative measurement scales, or indexes, assume that the indicators are causing the latent construct, in this case, the conditions of the IS model (Coltman et al. 2008; Diamantopoulos, Riefler & Roth 2008). These indicators compose carefully constructed formative measurement indexes, which scholars may use in model development (Diamantopoulos & Winklhofer 2001).

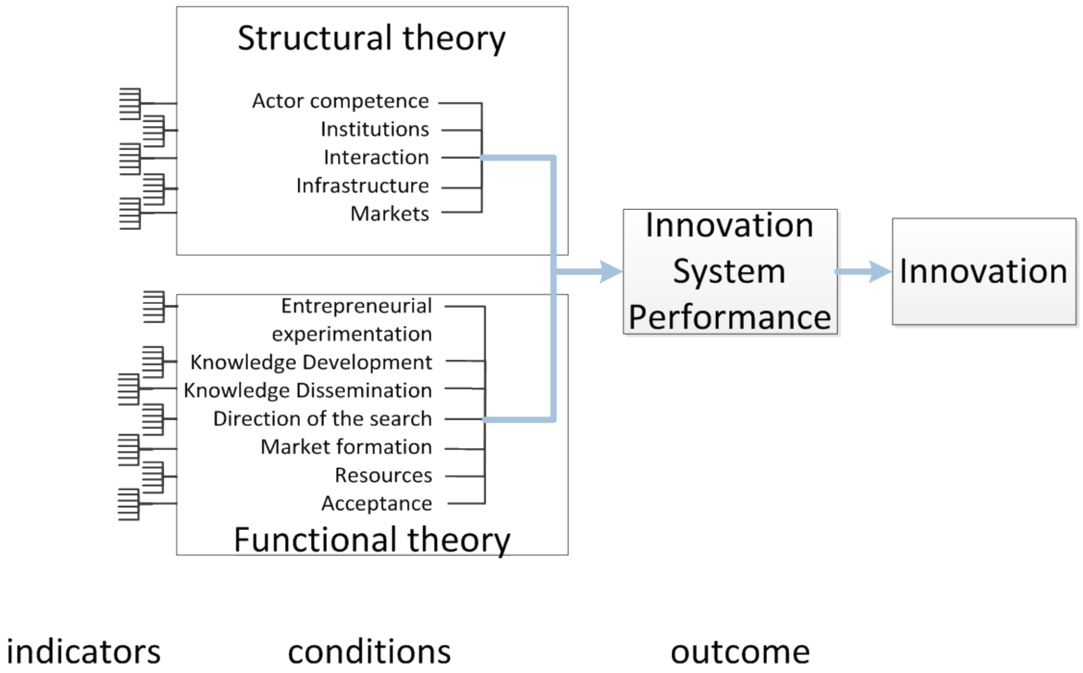


Figure 6.1 The structure of measurements, theories, and innovation outcomes
The calibration of the indicators and conditions is in Table 6.1.

The structural and functional theories claim to predict the performance of an IS through the strength of the innovation system conditions. A previous analysis (Chapter 5) of an innovation system using fsQCA identifies recurrent weaknesses in the conditions that the two theories propose. The previous analysis identifies market factors and interactions from structural theory as recurrently weak (Klein Woolthuis 2010; Klein Woolthuis, Lankhuizen & Gilsing 2005) drawing from the SIS theory. The previous analysis also identifies direction of the search and knowledge development from functional theory as recurrently weak (Bergek et al. 2008; Hekkert et al. 2007), drawing from TIS theory.

Given that four conditions are recurrently weak, and therefore, are frequently contributing to poor innovation system performance, recurrently weak indicators or combinations of indicators for these recurrently weak conditions that are leading to the lack of an innovation outcome may also exist. Examining individual indicators within the measurement model should allow finding those that most directly contribute to innovation system performance. In this context, the conditions are the latent constructs in the innovation system model resulting from a number of indicators. Occurrence of an innovation outcome implies innovation system performance.

QCA builds on the application of set theory to determine the cause of an outcome without assuming the additionality of the conditions, or the uniform effect of factors or a single solution. This fact makes QCA an approach apt to the analysis of complex systems (Berg-Schlosser et al. 2009; Woodside 2013).

The objectives of this article are to use QCA to understand the relationship between the formative indicators and four recurrently weak conditions for innovation system performance, and to determine whether a few critical indicators determine innovation system performance in this innovation system. A further objective is to consider how researchers may use formative measurement models in QCA as an alternative to regression and structural equation approaches (Woodside 2013). This work explores an approach to identifying both combinations of indicators that commonly lead to strong and weak conditions in an innovation system. The fsQCA identifies, qualitatively, the indicators that most associate with strength and weakness of a condition (Figure 6.1). The terms that this study uses consistently are indicator, condition, and outcome. This nomenclature maintains a consistent use of terms within this article, and results in no modification of the assumptions and practices of QCA. Linear regression assists in the selection of indicators. The reconstruction of the model, using only the indicators selected as important as conditions to explain innovation system performance and lack of innovation system performance outcomes, validates the analysis through the calculation of goodness of fit metrics.

6.2 Method

The data came from an online survey of innovation system actors (including researchers, industry personnel, and regulators) in projects in which the managers expected some change (innovation) at the commencement of the project and in which the research phase concluded successfully more than 2 years before the date of data collection. The study uses data from an innovation system within the domains of food safety (technology) in the Australian red meat industry (sector). Data covered 41 projects (cases), with an average of 5.8 respondents per case. A previous article describes the data collection process (Chapter 4). Briefly, the study measured the conditions from the structural and functional theories through the collection of responses to a number of indicator statements. Taking the mean of 6–7 indicators, each using a 7-point Likert scale, the study formed the indexes for the four conditions. The innovation system performance measure resulted from the identification of innovation, with indicators contextualized to the sectoral and technological system according to the OECD innovation typology (Organisation for Economic Co-operation and Development & Statistical Office of the European Communities 2005).

This study applies the fsQCA (Rihoux & Ragin 2009; Schneider & Wagemann 2010, 2012) using fs/QCA software version 2.5 (Ragin & Davey 2014). The conditions that this study investigated (Table 6.1) contribute repeatedly in the innovation system to poor innovation system performance. To identify significant indicators, the study performed a calibration using the same parameters for both the condition and indicators with two different points of indifference, which, in the context of this study, represent an indicator's level of achievement of an innovation system condition or innovation outcome (Table 6.1). At the lower level of certainty, the point of indifference is 3.8, whereas at the higher level of certainty the point of indifference is 4.9. A score of 4 on the Likert scale means that the average respondent "neither agrees nor disagrees," whereas a score of 5 means that the average respondent "somewhat agrees" that at least one example of innovation resulted from the project. A qualitative assessment of the configurations making up the complex solution considers the relative magnitude of each configuration's raw coverage and the number of configurations in which each indicator appears. The purpose of the assessment is understanding which indicators are most prominent in determining the condition, consistent with the qualitative roots of the method (Berg-Schlosser et al. 2009).

This study determined regression equations between calibrated condition indexes and calibrated single indicators using Microsoft Excel. The value of m, the slope of the line in the linear regression equation, is of interest because the condition index is the mean of all indicator values. A value close to 1.0 may suggest that the changes in the indicator contribute significantly to the condition index.

Table 6.1 Definition of parameters and their fuzzy set calibration at different levels of certainty of innovation system performance

Parameter type	Condition (abbreviation)	Indicator	Membership threshold	Non-membership threshold	Point of indifference low	Point of indifference high
Outcome	Innovation (INNOV)		6	2	3.8	4.9
Structural theory	Interactions (INTER, I)	a different backgrounds and expertise b common objectives or desires c common understanding was gained d trust was developed e dominant person/group f consensus among one or more groups g involvement from persons/groups external	6	2	4.5	5.1
	Markets (MARKET, M)	a demand for a solution was clear b size of the market justifies the PROJECT c results applied easily by a large number of companies d benefits outweigh the costs e effort in applying is small compared to the certain benefits f enough information to allow the results to be applied without significant additional expense	6	2	4.48	4.48
Functional theory	Knowledge Development (KNDEV, K)	a knowledge developed by the research b sufficient knowledge developed c useful knowledge developed d existing knowledge refined/defined e existing knowledge applied to new situation f the way to apply existing knowledge defined / refined	6	3	4.85	5.6
	Direction of the search (DIRECT, D)	a consultation before the work commenced b consultation during the research stage c consultation following the research stage d groups were involved in developing a vision for the e regulations or policy development helped to provide potential outcomes direction f requirements or expectations of customers were considered	6	3	4.5	5.1

6.3 Results

The identification of the indicators that contribute significantly to the weak conditions occurs through the application of two approaches. The fsQCA determines the configurations of the indicators sufficient to explain each condition and the negation of the condition. The study examines the quantitative linear relationship between the calibrated indicator and the calibrated condition data (Figure 6.2)[10].

6.3.1 Sufficiency of indicators for conditions and negation of conditions

The analysis of configurations of indicators arising from the fuzzy set truth table minimization for the condition of interaction (INTER) reveals three configurations when using calibration to a low certainty of innovation outcome, only one of which has a high coverage of the condition index (Table 6.2a, b). Four configurations have medium-high coverage when applying calibration for high innovation outcome certainty. Differing backgrounds and expertise of those involved (indicator a) seems essential, and often, but not always, occur with gaining common understanding (indicator c). Common objectives or desires (indicator b), development of trust (indicator d), and development of consensus (indicator f) are moderately common, but not essential, in cases with strong interactions. In most cases, strong interaction does not require either a dominant person/group (indicator e) or the involvement of external persons/groups (indicator g).

The configurations contributing to lack of interaction (~INTER) (Table 6.2a, b) suggest that a lack of involvement of external parties predicts lack of interaction (indicator g), as do lack of consensus and lack of trust (indicators f and d). The presence of the other indicators does not frequently appear to protect against weak interaction.

The logical minimization of the fuzzy set truth table for the market condition reveals seven configurations contributing to the MARKET solution, only four of which have high coverage of the condition index (Table 6.3). Sufficient market size for the product/technology (indicator b) seems essential for a strong market factor. Completion of the project, minimizing adoption expense (indicator f) often associates with a strong market factor. The inclusion (or lack of inclusion) of the other indicators in the solution does not affect the MARKET condition.

All seven configurations for weak market condition (~MARKET) have similar raw coverage of the solution (Table 6.3). The results frequently associate the negation of several indicators, such as clear demand (indicator a), easy, wide application (indicator c), and benefits outweighing costs with small effort (indicators d and e) with negation of the condition.

[10] Andreas Kiermeier, Statistical Process Improvement Consulting and Training Pty Ltd., produced figure 6.2

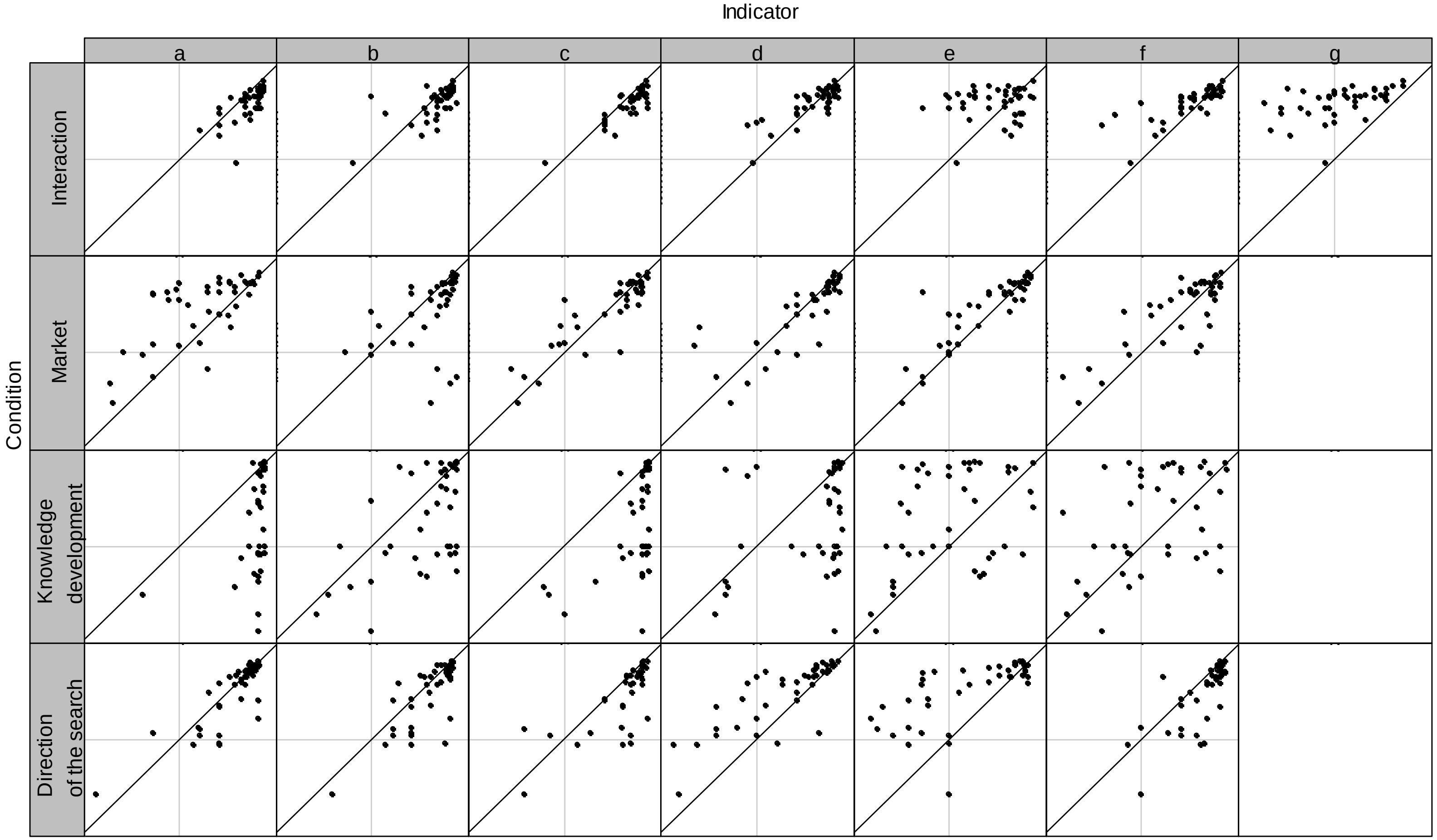


Figure 6.2 XY plots for the calibrated condition index against calibrated indicators
(for meaning of the letters a-g, refer to Table 6.1)

Table 6.2 fsQCA derived solution for the sufficiency of the indicators to explain the condition, INTERACTION, the negation of INTERACTION and the regression equation parameters for the condition against the indicator.

a) at a low certainty of INNOV

	Indicator	configurations for INTERACTION			configurations for ~INTERACTION			Regression parameters		
								m	b	r^2
a	different backgrounds and expertise	+	+	+	+	+	+	0.72	0.19	0.45
b	common objectives or desires	+	~	+	+	~	+	0.48	0.42	0.40
c	common understanding was gained	+	~	+	+	~	+	0.74	0.18	0.76
d	trust was developed	+	~	~	+	~	~	0.53	0.39	0.65
e	dominant person/group	0	+	+	~	+	+	0.08	0.77	0.02
f	consensus among one or more groups	+	~	~	+	~	~	0.42	0.50	0.61
g	involvement from persons/groups external	0	~	~	0	~	~	0.21	0.72	0.23
	Raw Coverage	0.89	0.10	0.17	0.76	0.5 3	07 4			

+ means inclusion, ~ means the inclusion of the negation, 0 indifference to inclusion, of the indicator in the condition

b) at a high certainty of INNOV

	Indicator	configurations for INTERACTION[1]				configurations for ~INTERACTION[2]					Regression parameters		
											m	b	r^2
a	different backgrounds and expertise	+	+	+	0	+	0	0	+	+	0.65	0.16	0.47
b	common objectives or desires	+	0	+	+	+	+	+	+	~	0.55	0.26	0.37
c	common understanding was gained	+	+	+	+	+	0	+	+	+	0.70	0.14	0.62
d	trust was developed	+	+	0	+	0	~	+	~	+	0.56	0.30	0.53
e	dominant person/group	0	+	~	~	+	+	~	~	+	0.08	0.65	0.01
f	consensus among one or more groups	+	0	+	~	~	~	~	+	0	0.58	0.32	0.67
g	involvement from persons/groups external	0	+	~	~	~	~	~	~	~	0.56	0.48	0.33
	Raw Coverage	0.83	0.63	0.44	0.31	0.77	0.64	0.62	0.53	0.52			

+ means inclusion, ~ means the inclusion of the negation, 0 indifference to inclusion, of the indicator in the condition

[1] 7 configurations were in the solution for INTER - cut off at 0.31 raw coverage for presentation here, [2] 8 configurations were in the solution for ~INTER - cutoff at 0.52 raw coverage for presentation here

Table 6.3 fsQCA derived solution for the sufficiency of the indicators to explain the condition, MARKET, the negation of MARKET and the regression equation parameters for the condition against the indicator

	Indicator	Configurations for MARKET							configurations for ~MARKET							Regression parameters		
																m	b	r^2
a	demand for a solution was clear	+	+	+	0	~	+	~	~	+	~	+	+	+	~	0.57	0.40	0.49
b	size of the market justifies the PROJECT	+	+	+	+	+	+	+	+	+	+	+	+	+	+	0.54	0.31	0.20
c	The results applied easily by a large number of companies	+	+	0	+	~	~	~	~	~	~	+	+	~	+	0.76	0.18	0.79
d	The benefits outweigh the costs	+	0	+	+	~	+	+	~	+	+	+	~	+	+	0.70	0.21	0.65
e	effort in applying is small compared to the certain benefits	0	+	+	+	~	~	+	~	~	+	~	+	+	+	0.78	0.20	0.78
f	enough information to allow the results to be applied without significant additional expense	+	+	+	+	~	~	~	~	~	~	+	+	+	+	0.67	0.27	0.67
	Raw Coverage	0.73	0.73	0.7	0.81	0.15	0.17	0.18	0.58	0.52	0.56	0.60	0.57	0.55	0.68			

+ means inclusion, ~ means the inclusion of the negation, 0 indifference to inclusion, of the indicator in the condition

The logical minimization of the fuzzy set truth table for knowledge development (KNDEV) reveals four configurations, of which only two contribute significantly to the coverage of the solution (Table 6.4a, b). Knowledge development within the project (indicator a) is usually essential, though in some cases this knowledge seems insufficient or useless (indicators b and c). Existing knowledge (indicators d and e) is rarely a sufficient substitute for knowledge development.

Four configurations contribute to the negation of knowledge development (~KNDEV) solution, but one has much higher coverage than the others do (Table 6.4a, b). Lack of sufficient or useful knowledge, whether developed within the project or not, and defined application of knowledge (indicators b, c, d, e, and f) all may contribute to weak knowledge development, often when combinations of indicators are weak.

The logical minimization of the fuzzy set truth table reveals four configurations in the solution for direction (DIRECT), of which one provides much more coverage of the condition index than the others do (Table 6.5a, b). To contribute to a high DIRECT index, the process requires consultation before, during, and following the research stage (indicators a, b and c). The consideration of customer requirements and expectations are also usually essential (indicator f). To provide direction, the process does not require the development of a vision for outcomes of the project (indicator d) and consideration of regulatory/policy positions (indicator e).

For the negation of DIRECT, three of the four configurations in the solution provide high coverage (Table 6.5a, b). The lack of development of a vision for outcomes of the project (indicator d) and lack of consideration of regulatory/policy positions (indicator e) frequently associate with negation of DIRECT.

A qualitative assessment of these results allows the determination of indicators that are most prominent in configurations that explain the four conditions. At least one indicator for each condition can represent the relationship between these conditions and innovation system performance. The study considers the association of each indicator with configurations with high raw consistency for both low and high levels of innovation certainty and selects seven indicators. The indicators are (1) inclusion of project teams with different backgrounds and expertise (Interaction a), (2) sufficient size of market to justify the project (Market b), (3) the research's development of knowledge (Knowledge development a), (4, 5, and 6) consultation before, during, and following the research stage (Direction a, b, c), and (7) consideration of the requirements or expectations of customers (Direction f).The abbreviations are Ia, Mb, Ka, Da, Db, Dc, and Df, respectively.

Table 6.4 fsQCA derived solution for the sufficiency of the indicators to explain the condition, Knowledge Development (KNDEV), the negation of Knowledge Development and the regression equation parameters for the condition against the indicator.

a) at a low certainty of INNOV

	Indicator	configurations for KNDEV				configurations for ~KNDEV				regression parameters		
										m	b	r^2
a	Knowledge developed by the research	+	+	0	+	0	+	+	+	0.96	0.24	0.13
b	Sufficient knowledge developed	+	+	~	~	~	~	+	+	0.78	0.04	0.36
c	Useful knowledge developed	+	+	~	0	~	0	+	+	1.04	0.28	0.28
d	Existing knowledge refined/defined	+	0	~	~	~	~	+	~	0.42	0.32	0.12
e	Existing knowledge applied to new situation	0	~	~	~	~	~	0	~	0.42	0.44	0.15
f	The way to apply existing knowledge defined / refined	0	+	~	~	~	~	~	+	0.51	0.36	0.22
	Raw Coverage	0.89	0.46	0.08	0.12	0.24	0.32	0.59	0.23			

for configurations: + means inclusion, ~ means the inclusion of the negation, 0 indifference to inclusion, of the indicator in the condition

b) at a high certainty of INNOV

	Indicator	configurations for KNDEV				configurations for ~KNDEV			regression parameters		
									m	b	r^2
a	Knowledge developed by the research	+	+	+	+	+	0	+	0.73	-0.12	0.13
b	Sufficient knowledge developed	+	+	0	~	~	~	~	0.55	0.17	0.24
c	Useful knowledge developed	+	+	+	~	+	~	~	0.61	0.02	0.19
d	Existing knowledge refined/defined	0	+	~	+	0	~	+	0.32	0.30	0.08
e	Existing knowledge applied to new situation	~	0	~	~	~	~	~	0.34	0.42	0.06
f	The way to apply existing knowledge defined / refined	0	0	~	+	~	~	+	0.43	0.36	0.12
	Raw Coverage	0.67	0.81	0.23	0.12	0.45	0.25	0.14			

Table 6.5 fsQCA derived solution for the sufficiency of the indicators to explain the condition, DIRECTION of the search, the negation of DIRECTION and the regression equation parameters for the condition against the indicator

a) at a low certainty of INNOV

	Indicator	configurations for DIRECT				configurations for ~DIRECT				regression parameters		
										m	b	r^2
a	Consultation before the work commenced	+	0	+	+	+	+	+	~	0.85	0.10	0.70
b	Consultation during the research stage	+	+	+	+	+	+	+	+	1.00	0.05	0.62
c	Consultation following the research stag	+	+	0	+	+	0	+	+	0.80	0.10	0.56
d	Groups were involved in developing a vision for the potential outcomes	0	+	~	~	~	~	+	+	0.57	0.40	0.67
e	Regulations or policy development helped to provide direction	0	~	~	~	~	~	~	~	0.43	0.52	0.47
f	Requirements or expectations of customers were considered	+	+	+	0	0	+	+	+	0.97	0.05	0.57
	Raw Coverage	0.93	0.35	0.29	0.28	0.79	0.81	0.82	0.58			

for configurations: + means inclusion, ~ means the inclusion of the negation, 0 indifference to inclusion, of the indicator in the condition

b) at a high certainty of INNOV

	Indicator	configurations for DIRECT[1]				configurations for ~DIRECT[2]				regression parameters m	b	r^2
a	Consultation before the work commenced	+	+	+	+	0	~	0	~	0.85	0.07	0.67
b	Consultation during the research stage	+	~	0	~	+	0	~	~	0.82	0.07	0.59
c	Consultation following the research stag	+	+	+	+	+	+	~	+	0.84	0.01	0.59
d	Groups were involved in developing a vision for the potential outcomes	0	+	~	~	~	~	~	~	0.74	0.26	0.69
e	Regulations or policy development helped to provide direction	0	+	~	0	~	~	~	0	0.61	0.35	0.59
f	Requirements or expectations of customers were considered	+	0	0	+	+	0	0	+	0.85	-0.01	0.63
	Raw Coverage	0.90	0.62	0.27	0.26	0.66	0.60	0.53	0.50			

for configurations: + means inclusion, ~ means the inclusion of the negation, 0 indifference to inclusion, of the indicator in the condition

[1] 6 configurations were in the solution for DIRECT - cutoff at 0.26 raw coverage for presentation here [2] 6 configurations were in the solution for ~DIRECT - cutoff 0.50 for presentation here

Seven indicators present an association with the failure to innovate. These indicators are (1) lack of trust (Interaction d), (2) results that a large number of companies do not apply easily (Market c), (3) the effort to apply is not small compared to benefit (Market e), (4) existing knowledge not refined/defined (Knowledge development d), (5) knowledge not applied to a new situation (Knowledge development e), (6) groups not involved in developing a vision for potential outcomes (Direction d), and (7) regulation/policy not helping to provide direction (Direction e). Their abbreviations are Id, Mc, Me, Ke, Kf, Dd, and De, respectively.

6.3.2 Linear regression

The linear regression correlations between indicators and conditions (primarily the slope of the line, m), with calibration for fuzzy set membership, follow one of four basic patterns (Figure 6.2). A positive correlation might exist with a high slope (m) approximating Y = X, with greater or lesser variation (in r^2) around the line (for example, Figure 6.2 graph Ic). Especially when the r^2 is high, a high value for m represents both high necessity and high sufficiency of indicators for the condition. A high value for the condition (Y) might exist, irrespective of the indicator (X) which represents the sufficiency of the indicator for the condition (Schneider & Wagemann, 2012) and results in low slope (for example, Figure 6.2, graph Ig). A high value for the indicator (X) might exist irrespective of condition (Y) which is representative of the necessity of the indicator (Schneider & Wagemann, 2012), and a high slope (for example, Figure 6.2, graph Ka) should all the cases be similar. The Figure shows X Y pairs where no relationship exists between the indicator and condition (for example, Figure 6.2 graph Ke).

For the condition of interaction, the slopes for the indicators with backgrounds and expertise different from those involved (indicator a) and gaining common understanding (indicator c) are high, thus indicating a positive correlation between the indicator and condition. The indicator for involvement of a dominant person or group (indicator e) has a low value for m. The regression lines for INTER and lack of involvement of external parties (indicator g), lack of consensus (indicator b), and lack of trust (indicator d) have moderately low values for m.

All indicators of the MARKET condition have moderate to high slope and those with the highest slopes have relatively high values for r^2. Four indicators, easy application of results (indicator c), benefits outweighing costs (indicator d), small effort to apply results (indicator e), and completion of the project to the point where the organization can apply results without significant additional expense (indicator f), have both moderately high m and r^2. Sufficient market size for the product/technology (indicator b) seems essential and has a moderate slope.

The relationship between indicators and KNDEV, as the high slope of the regression line indicates, suggests a strong relationship between the development of sufficient and useful new knowledge (indicators a, b, and c), but quantitative variability (low r^2). The other indicators all have moderate slope and low r^2 for the regression line.

The relationship between the indicators for consultation before, during, and following the research stage (indicators a, b, and c) and the DIRECT condition is high with moderate consistency (r^2). The consideration of the expectation of customers (indicator f) also has high slope and r^2. The development of a vision for outcomes of the project (indicator d) and consideration of regulatory/policy positions (indicator e) have moderate values for m and r^2.

The study selects seven indicators, using fsQCA, that most closely associate with strong conditions (Ia, Mb, Ka, Da, Db, Dc, and Df), and therefore, with innovation system performance. Six of them have a value of m > 0.7. The study selects another four indicators, for comparison, that do not explain the strong conditions (If, Ke, Dd, and De); their maximum value for m = 0.57 and three out of four have m <0.45. High sufficiency of indicators for the condition, correlates with high values for m, but not always. High m alone is not sufficient to predict selection through a qualitative assessment of fsQCA as an indicator.

6.3.3 Evidence for the validity of indicators for their associated condition

This study searches for a few key indicators that contribute strongly to the formation of the four frequently weak conditions in the innovation system under study. A question that arises is whether these indicators are truly representative of the condition with which they associate. The fsQCA assesses the necessity and sufficiency of the single indicators for the conditions they help form, as well as for the other conditions. The study calculates the consistency and coverage of the necessity of the seven indicators of the conditions, using the calibration of the lower certainty of innovation outcome and the associated condition. The study also compares other conditions (Table 6.6). The consistency, coverage, or both, of the conditions with the associated indicator are always higher than the consistency and coverage of any other indicator–condition pair.

Table 6.6 The consistency and coverage of necessity relationships between selected indicators and conditions.
The results in **bold** are for the indicator - condition pairs that are associated in the model. The <u>underlined</u> numbers represent the consistency or coverage that is greater than the pair associated in the model.

Indicator	Consistency				Coverage			
	INTER	MARKET	KNDEV	DIRECT	INTER	MARKET	KNDEV	DIRECT
Ia	**0.99**	<u>0.98</u>	0.97	0.99	**0.92**	0.83	<u>0.72</u>	0.86
Mb	0.94	**0.97**	0.79	0.83	<u>0.93</u>	**0.88**	<u>0.73</u>	0.88
Ka	0.99	<u>0.99</u>	**1.00**	0.92	0.87	0.80	**0.70**	0.82
Da	0.93	0.95	0.67	**0.97**	<u>0.96</u>	<u>0.89</u>	<u>0.76</u>	**0.94**
Db	0.94	0.97	0.73	**0.98**	<u>0.94</u>	0.88	<u>0.74</u>	**0.92**
Dc	0.94	0.96	0.65	**0.99**	<u>0.93</u>	0.86	<u>0.73</u>	**0.91**
Df	0.96	<u>0.98</u>	0.78	**0.99**	<u>0.93</u>	0.87	<u>0.73</u>	**0.90**

6.3.4 Ability of selected indicators to predict an innovation or lack of innovation outcome

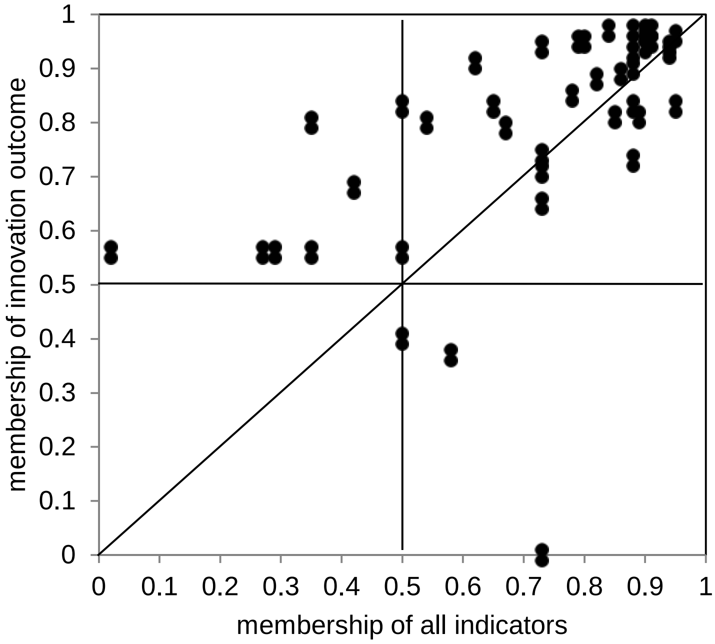
Truth table minimization allows evaluating the ability of the selected indicators to predict innovation or lack of innovation. The fsQCA complex solutions (Table 6.7) demonstrate high solution coverage and at least moderate consistency (Figure 6.3). The fsQCA with the negated innovation (~INNOV) outcome produces a complex solution (Table 6.7), demonstrating high solution coverage and consistency. All four configurations have moderate raw coverage and the indicators feature in the configurations with the highest coverage. These results suggest that these seven indicators contribute significantly to the lack of innovation outcome.

Scholars (Magetti & Levi-Faur 2013; Woodside 2014) cite 0.80 as an acceptance criterion for consistency of sufficiency, whereas others cite 0.74 (Woodside 2013) or are mute (Schneider & Wagemann 2010). The consistency of two of these four models falls slightly short of these criteria but have high raw coverage. Each configuration consists of six of the seven indicators, and the overwhelming majority of the configurations 'make sense' against theory. These results show, if this is the only evidence to consider, that these seven of twenty-five indicators (more, including the indicators for the conditions that this study does not consider) are sufficient to explain the innovation outcome.

6.3.5 Alternate causal configurations for innovation

To assess the adequacy of the causal conditions for the INNOV outcome, the study compares the goodness of fit parameters for the selected indicators with alternate sets of indicators. The alternate sets of indicators for comparison are the next best indicators to the selected ones, a set of random indicators, and the indicators that this study chooses as causal conditions of ~INNOV (Table 6.8). This study performs fsQCA on calibrated data using the lower certainty of innovation parameters. In all cases, the qualitative and quantitative parameters for goodness of fit are not as satisfactory as those for the chosen set of indicators, though these parameters are not always much inferior to the selected set. The model might be satisfactory by itself, but in the light of these other analyses, the differences are not significant.

a) low certainty of innovation outcome



b) high certainty of innovation outcome

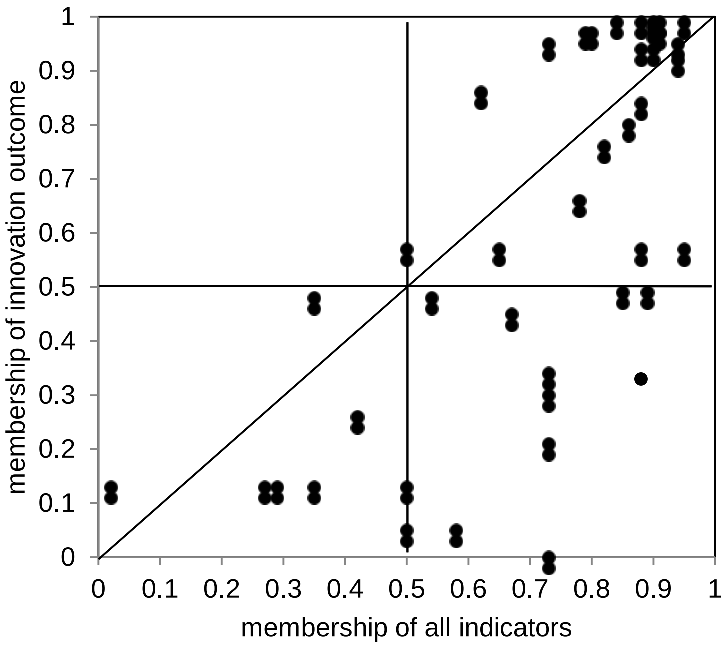


Figure 6.3 XY plots of outcome against indicators

Table 6.7 Complex solution to truth table minimization

Outcome	Level of certainty	Consistency threshold	Causal configurations, solution coverage and consistency	Raw coverage	Unique coverage	Consistency
INNOV	low	0.92	Ia*Mb*Ka*Da*Db*Df	0.87	0.02	0.95
			Ia*Mb*Ka*Db*Dc*Df	0.88	0.02	0.95
			Ia*Mb*Da*Db*Dc*Df	0.86	0.01	0.94
			Ia*~Mb*Ka*Da*Db*Dc*~Df	0.11	0.01	0.99
			solution coverage: 0.91			
			solution consistency: 0.94			
INNOV	high	0.71	Ia*Mb*Ka*Da*Db*Df	0.92	0.00	0.75
			Ia*Mb*Ka*Db*Dc*Df	0.94	0.01	0.76
			Ia*Mb*Da*Db*Dc*Df	0.92	0.00	0.76
			Ia*~Mb*Ka*Da*Db*Dc*~Df	0.12	0.00	0.81
			solution coverage: 0.94			
			solution consistency: 0.73			
~INNOV	low	0.76	~Mc*~Me*~Ke*~Kf*~Dd*~De	0.63	0.12	0.94
			Id*Mc*Me*~Ke*~Kf*~Dd*~De	0.63	0.09	0.78
			Id*~Mc*Me*Ke*Kf*~Dd*~De	0.48	0.07	0.76
			solution coverage: 0.82			
			solution consistency: 0.73			
~INNOV	high	0.79	~Mc*~Me*~Kf*~Ke*~Dd*~De	0.33	0.06	0.97
			Id*Mc*Me*~Kf*~Ke*~De	0.43	0.14	0.83
			Id*~Mc*Me*Kf*Ke*~Dd*~De	0.29	0.04	0.89
			Id*~Mc*~Me*Ke*Kd*~De	0.22	0.01	0.79
			solution coverage: 0.58			
			solution consistency: 0.82			

Table 6.8 Goodness of fit parameters for alternative sets of causal conditions for the INNOV outcome

Approach to construction	Conditions	Consistency threshold	Number of configurations	Max number of conditions in the configuration with the highest raw coverage	Solution coverage	Solution consistency
Chosen indicators for INNOV (Table 6.7)	Ia, Mb, Ka, Da, Db, Dc, Df	0.92	4	6	0.91	0.94
Next best indicators for INNOV	Ic, Mf, Kb, Kc, Df	0.87	3	4	0.88	0.92
Random selection	Id, Me, Kd, Dd, De, Df	0.91	4	4	0.87	0.94
Chosen indicators for ~INNOV	Id, Mc, Me, Ke, Kf, Dd, De	0.83	8	5	0.81	0.96

6.4 Discussion

The findings apply only to the innovation system for the period of collection of data, therefore, their generalizability is limited. However, the understanding that the analysis of this innovation system produces, may also apply to innovation systems that are similar in nature.

6.4.1 Analysis of this innovation system

In this dataset, a small number of selected key indicators are able, not only to contribute significantly to the conditions they help to form, and to correlate highly with the condition through regression analysis, but also to collectively produce configurations that have at least moderate consistency in explaining the innovation outcome. The necessity of the indicator for the construct and the frequency of inclusion in sufficient configurations with high coverage all determine the significance of contribution of the indicator to forming a construct. However, the analysis of the four conditions always presents several alternative configurations with many indicators and high coverage. When using alternative indicators as conditions for an innovation outcome, the results are almost as acceptable as with the selected indicators. These observations suggest that many indicators are almost equally necessary for strength of a condition and that many indicators are almost equally able to predict an innovation outcome.

The configuration that predicts ~INNOV with a small number of indicators that represent the four recurrently weak conditions results in high coverage. Interestingly, the configurations are quite asymmetric with those causal for INNOV; the indicators most responsible for weak conditions are not simply the absence of the indicators for strong conditions. However, the good fit of the selected indicators for ~INNOV when they apply to the INNOV outcome, suggests that the differences in the significance of indicators is only small.

The implication of these observations is that, just as innovation system performance requires all conditions (Chapter 4), the conditions that contribute to innovation system performance require a large number of indicators.

6.4.2 Innovation system theory

The innovation system failure theories for both sectoral and technological innovation systems suggest that all elements (conditions) need to be present to result in innovation system performance. Using the innovation system of this study, the literature proves that these theories are valid (Chapter 4). This study shows that most, if not all, of the indicators in the survey instrument are also contributors to the strength or weakness of the studied conditions.

The set of selected indicators, for all four recurrently weak conditions, are diverse, but may have a potential link. The selection of a diverse project team (Interaction a) can facilitate consultation (Direction a, b, c) and consideration of customer requirements (Direction f). This observation supports the previous observation that the structural theory elements provide a platform for the operation of the functional theory elements.

6.4.3 FsQCA, formative measurement models, and regression

The use of a formative measurement model for conditions, which subsequently contributes to the outcome, is an epistemologically consistent approach. Formative measurements systems and QCA are consistent methods because they both look into conditions/indicators that cause/form the outcome/latent variable.

The use of QCA for analysis of the measurement model provides evidence for convergent, divergent, and nomological validity (Hair et al. 2014) of the measurement model. Logical minimization of the truth table to (multiple) causal recipes requiring (largely similar) multiple indicators is evidence of convergent validity. The goodness of fit parameters for associated indicator-condition pairs in comparison to non-associated pairs is evidence of divergent validity. Validation of formative measurement models is problematic (Diamantopoulos, Riefler & Roth 2008; Diamantopoulos & Winklhofer 2001) and QCA methods deserve greater consideration for this purpose. This analysis is somewhat preliminary. The development of software that allows multiple comparisons of indicator-condition pairs using QCA and comparison of goodness of fit estimates for indicators and conditions would facilitate the development of QCA in formative measurement models.

This study provides an example of the potential problems of taking a number of conditions and assuming that the model is the only explanatory possibility simply because the goodness of fit parameters are acceptable.

This study uses regression analysis as a visualization tool and confirmation of the fsQCA results. The use of m as a parameter probably works because of the construction of the condition index. r^2 is helpful as a summary parameter for the conformity of the association. The differences in the regression and QCA results illustrate the concerns with overreliance on linear regression (Armstrong 2012; Woodside 2016).

6.5 Conclusion

The use of fsQCA on the data from a single innovation system suggests that many indicators are almost equally significant in forming the four recurrently weak conditions from the structural theory and functional theory. This finding suggests that, like the requirement for all conditions to be effective for innovation system performance, many indicators contribute to the effectiveness of those conditions. Even though the contribution needs many indicators, fewer indicators demonstrate significant variability that would affect innovation system performance in the innovation system under study. The application of policy or management actions can correct poor innovation system performance.

The QCA method is effective for the identification of innovation system weaknesses that may contribute to poor innovation system performance. Through this preliminary study, the use of QCA for validation of formative measurement models is promising and is worthy of further investigation.

The survey instrument is valid and would be useful as a diagnostic for innovation system performance. Innovation system performance would greatly benefit from the application of the survey instrument to other innovation systems, further development of the ideas that this article presents for validation of the formative measurement system using fsQCA, and further understanding of the application of innovation system thinking at the level of projects.

7

The significance of actors in innovation system performance[11]

7.1 Introduction

The activities of actors, particularly the importance of networks and the role of intermediaries in innovation systems have received attention with respect to system level policy implications in the innovation literature (Allen, J, James & Gamlen 2007; Howells 2006; Klerkx & Leeuwis 2008; Linton 2000); however, these actors have yet to be integrated into a useful conceptual framework that explains innovation system performance at the project level. Innovation systems thinking had its genesis in the 1980s initially as a reaction against the simplicity of a linear model of innovation based on neo-classical economics (Sharif 2006) and developed in an attempt to "describe, understand, explain - and perhaps influence - processes of innovation" (Edquist, Charles 1997, p. 2). The work described in Chapter 5 found that innovation systems theories can be applied as a useful managerial tool to understand and explain poor performance of innovation systems at the project level. However, the role of networks and, to a lesser extent, the role and functions of intermediaries, even though acknowledged in innovation system frameworks, have not been systematically investigated with respect to project-level performance. The purpose of this article is to examine the contributions of networks and intermediaries to innovation system performance at the project level.

[11] submitted

Performance of an innovation system at the project level, can be measured by the occurrence of innovation which may include changes to product, process, supply chains and business models (Schumpeter 1934). The innovation system chosen for study was that for food safety in the Australian red meat industry which is at the intersection of sectoral and technological innovation systems. All the projects were managed by MLA which is a government/industry-funded innovation intermediary with a mandate to deliver research and development services in this sector (Core & Australian Department of Agriculture Fisheries and Forestry 2009). Multiple cases of projects with a potential innovation outcome within this innovation system are examined. The actors, involved in the system are defined and include: (1) researchers, often based in universities and research institutes; (2) firms in the industry; (3) industry associations; (4) the intermediary; (5) the government as a regulator; (6) suppliers; (7) customers; and (8) entrepreneurs, who exploit the innovations in the pursuit of opportunities (see, Kilelu et al. 2011; Klerkx & Leeuwis 2008). In the present study their effectiveness is explored through the opinions of other actors in the system and their impact on innovation system performance. The networking of actors at both the system and project level is defined, and links between the actors' involvement and effectiveness and the effective performance of the innovation system is investigated.

7.2 Literature Review

7.2.1 Innovation Systems

Four major approaches have been taken to the study of innovation systems including: (1) national; (2) regional; (3) sectoral; and (4) technological. The approach chosen as an analytical lens depends on the question being answered (Carlsson et al. 2002). Studies on national and regional innovation systems are often general, and the findings could easily be applied to other innovation systems approaches. For example, Castellacci and Natera (2013) discuss the coevolution of innovative capability and absorptive capacity in national systems, and Guan and Chen (2012) discuss the character of national systems in terms of knowledge production and commercialisation processes, both of which could be applied to technological or sectoral systems. Chung (2002) suggests that the regional innovation system concept is useful for generation of both national and sectoral innovation systems. However, neither national nor regional innovation systems approaches tend to be fine grained enough to provide practical managerial recommendations at the project level. The SIS approach, focussing on the innovation of a single industry sector, and the TIS approach, focussing on a technology, are the most immediately relevant at the level of a project. They deal with the environment in which a project is situated (Pitt & Nelle 2008) and the factors that positively or negatively affect the diffusion and adoption of technology (Negro, Hekkert & Smits 2007).

The sectoral (Breschi & Malerba 1997) and technological (Carlsson & Stankiewicz 1991) approaches are useful in understanding both the processes and potential failures of innovation systems, and frameworks for diagnosing the causes of innovation system failure have been developed using both approaches (Bergek et al. 2008; Klein Woolthuis, Lankhuizen & Gilsing

2005). The sectoral and the technological approaches acknowledge the importance of actors in the innovation system. For example, the SIS failure model (Klein Woolthuis, Lankhuizen & Gilsing 2005) seeks to understand the problems situated at the intersection of actors and system elements; while the TIS failure model (Bergek et al. 2008) acknowledges networks as fundamental to the functions that occur within the system. The elements of both the sectoral (Klein Woolthuis 2010; Klein Woolthuis, Lankhuizen & Gilsing 2005) and technological (Bergek et al. 2008; Hekkert et al. 2007) system failure approaches have been constructed and tested as theories and are able to explain innovation system performance (Chapter 4). In addition, both sectoral and technological innovation system approaches are used in policy and practice (Manjón & Merino 2012; Rosales-Carreón & García-Díaz 2015).

While the importance of networks is acknowledged (Allen, J, James & Gamlen 2007; Johnston & Linton 2000; Powell & Grodal 2005) and the kinds of actors required to be present and effectively interact in an innovation system have been defined (Allen, TJ, Tushman & Lee 1979), there are few examples in the literature of network analysis that are specific to innovation systems (Sapsed, Grantham & DeFillippi 2007). The exception is work by Musiolik and Markard (2011) and Musiolik et al. (2012) who used social network analysis to understand formal and informal network development in emerging technologies, and how the development of the network brought sufficient resources to the innovation system.

7.2.2 Intermediaries

The identification of actors has typically taken an organizational approach (Jacobsson, S & Johnson 2000) that may include suppliers and users of a product or service, as well as institutions such as research, financial, and governmental organisations (Malerba 2004). While the role of intermediaries, or bridging organisations, was identified in the early innovation systems literature (Carlsson & Stankiewicz 1991), the critical role of intermediary actors has largely been neglected in later research on innovation systems, with the exception of work by scholars such as Howells (2006); Klerkx and Leeuwis (2008a,b, 2009); Kilelu et al. (2011); Klerkx, Aarts and Leeuwis (2010);, and Edler and Yeow (2016); none of whom investigated the contribution of intermediaries in a quantitative way.

Innovation system intermediaries link sources of technology with those who can develop it, commercialize or apply it and appropriate value from its commercialization or application, compensating for the structural weaknesses of the system (Carlsson & Stankiewicz 1991). Innovation system intermediaries (Howells 2006) have also been conceptualized as integrators (Hobday, Davies & Prencipe 2005), brokers (Batterink et al. 2010), and orchestrators (Dhanaraj & Parkhe 2006); all fulfilling the same function in the innovation system - linking people and technologies to create tangible outputs from innovation (Edler & Yeow 2016). Kilelu, et al. (2011) note that innovation system intermediaries have six basic functions including: (1) the understanding, articulation and stimulation of demand for the innovation; (2) network brokering; (3) serving as knowledge brokers; (4) managing the innovation process within and between the system actors; (5) capacity building; and (6) creating the institutional framework that facilitates commercialization of the innovation.

Innovation system intermediary actors may be individuals, organizations, or institutions such as technology brokers, university extensions services, government technology transfer programs, and research organisations. These actors are a critical component of all innovation systems and especially so in SIS (Pitt 2007).

Individuals, organizations and institutions that produce technology tend to function within various technology platforms, regional, or sector-based ecosystems and frequently have a 'lead organization' that sets the rules and coordinates the networked ecosystem (Dhanaraj & Parkhe 2006; Ritala, Armila & Blomqvist 2009) providing enabling leadership and creation of value. For example, Apple or Microsoft are firms that lead a sector based around their unique technology platforms (Moore 1993; Nambisan & Baron 2013). While lead organizations such as Apple and Microsoft have technological advantages that embuses them with dominance in their SIS (Dhanaraj & Parkhe 2006); smaller organizations such as research and development commercialization institutions such as UniQuest which commercialized Gardasil® (http://uniquest.com.au/filething/get/8631/Gardasil%20Commercialisation%20Story.pdf) may also take a leadership position in a sector and play the role of integrator (Sabatier, V, Mangematin & Rousselle 2010). These technology leadership capabilities are both at the individual and organizational level (Ritala, Armila & Blomqvist 2009).

Industry member-based organisations that have political or representative functions may also act as intermediaries in the development of national innovation ecosystems where they can articulate industry support for innovation policies and provide a source of funds (Watkins et al. 2015). Likewise, government and non-government institutions (semi-autonomous, owned companies, foundations) may function as both technology providers and intermediaries in technological transitions, such as in sustainable energy (Kivimaa 2014). Research institutes may also operate as intermediaries within SIS (Chunhavuthiyanon & Intarakumnerd 2014).

7.3 Methods

The cases were defined as projects in which some change (innovation) was expected at the commencement of the project and in which the research phase was successfully completed more than two years before the date of data collection allowing time for the innovation to develop. The internal records of MLA were used as a basis to define the projects conducted. Data were collected for every project meeting the case definition through an on-line survey (Appendix 2) of people who had some involvement in, or knowledge of, each project, both those identified by the project manager, knowledgeable informants and by other survey respondents. Respondents were provided with a description of the project, the years in which the research was performed, research organisation and principal researchers involved, the nature of the project, available publications and initial step towards an outcome. Respondents had the option of not answering questions or responding that they were not in a position to know the answer. The survey instrument asked questions to determine whether innovation occurred, and about the involvement of actors, including the intermediary organisation in the project and whether that involvement was effective (see Appendix 2).

Innovation system performance was measured through the occurrence of innovation. Innovation was identified, according to the typology of the Organisation for Economic Co-operation and Development (2005), tailored appropriately to the sectoral (red meat) and technological (food safety) domain. The maximum Likert-scale score to an indicator of innovation was used as the measure of innovation system performance, because each project may only result in one innovation outcome. Respondents were asked, for each potential actor, whether that actor had been involved in the project (scored as no=0, yes=1). Regardless of involvement, respondents were asked whether the (lack of) involvement had a negative, neutral or positive impact on achieving the objectives of the project (scored as negative = -1, neutral = 0, positive =1). Questions were also asked to assess the strength of innovation system conditions. The conditions of interaction and market, identified by SIS failure theory (Klein Woolthuis 2010; Klein Woolthuis, Lankhuizen & Gilsing 2005) and knowledge development and direction, identified by TIS failure theory (Bergek et al. 2008) were selected for analysis based on these being recurrently weak conditions in this innovation system (Chapter 5). The score for innovation system conditions was an average of the Likert scores for all respondents to all indicators in the survey instrument.

FsQCA methods were applied (Rihoux & Ragin 2009; Schneider & Wagemann 2012). QCA arises from the case study tradition in which there is a desire to analyse the results of multiple case studies (including small numbers of cases) and seeks to find the least complex set of variables causally related to the outcome, while acknowledging the possibility that multiple paths may lead to the same outcome (Rihoux 2013). Meuer, Rupietta and Backes-Gellner (2015) have used fsQCA to identify and characterise innovation systems. An example of the set-theoretic Boolean logic employed in QCA is that the analysis seeks both necessary and sufficient causal conditions to explain the outcome (Ragin 2006). Analysis was conducted using fs/QCA software version 2.5 (Ragin & Davey 2014). Statistical tests (two sided t-test assuming unequal variances) were applied using Microsoft Excel[12].

7.4 Results

A survey was conducted to collect data on 41 projects (cases). Two hundred and thirty nine responses to the survey instrument (Table 7.1) were received from 100 recruited respondents (57% recruitment rate) with some respondents recruited to respond regarding more than one project. A total of 76% of surveys sent to recruited respondents were returned. Additionally, the program manager at MLA responded to the survey instrument for all projects. Less than half (43%) of the responses came from those identifying as researchers and the program manager responses

[12] Dr Andreas Kiermeier and Dr David Jordan provided helpful statistical advice.

represented 15.7% of all responses, which does not unduly privilege researcher or program manager. Some respondents were unable to answer the questions about the participation of a substantial number of actors for the project they were assessing.

When analysis was conducted employing fuzzy set methods (fsQCA) set membership needed to be defined and degree of set membership determined. A key aspect of calibrating fuzzy set membership is the point of indifference, the point that separates cases more in the set than out of the set from those that are more out of the set than in the set. Two approaches to fuzzy-set calibration in QCA are suggested in the literature. One approach (Schneider & Wagemann 2012) promotes the selection of points that are based on theoretical knowledge and empirical evidence about the condition or outcome and the other (Woodside 2010, 2013, 2014) promotes the use of statistically selected values for calibration. Both approaches have been used here, appropriate to their purpose. The point chosen, from previous work(Chapter 5), to represent the point of indifference in membership of the innovation set was 4.8 on a 7 point Likert scale which was close to the point at which an average respondent "somewhat agrees" that at least one example of innovation resulted from the project. Using this parameter for fuzzy set calibration, 13 cases had <0.5 membership of the set of projects with innovation outcomes (~INNOV), and the remainder had >0.5 membership of the set of projects with an innovation outcome (INNOV). The involvement of actors was determined by asking each respondent whether they were aware of the involvement of other actors in the project (0=no, 1=yes).

Furthermore, respondents were asked to assess the effectiveness of the actors based on whether the involvement (or lack of involvement) contributed positively, or negatively to the achievements of the project (-1=negative, 0=neutral, 1=positive). Scores for involvement and effectiveness were an average of all responses. An arbitrary calibration of involvement and effectiveness of actors in each project were chosen to result in about half the cases being totally within the set, and about 10% of cases being completely outside their respective sets, with the remainder variably within the set.

Table 7.1 Actors' Involvement and Effectiveness in the innovation system

Actor	Number of substantially complete responses from this actor	Number of responses scoring this actor's involvement	Average Involvement score*	Average Effectiveness score**
Researcher	83	247	1.00	0.99
Industry firm	23	216	0.83	0.72
Industry association	8	189	0.62	0.49
Intermediary	33	242	0.94	0.87
Government	23	193	0.51	0.40
Supplier	5	180	0.38	0.31
Customer	0	181	0.17	0.10
Entrepreneur	0	173	0.40	0.38
Program manager	41	na	na	na

na - not applicable - not included in the survey
* 0=no, 1=yes **-1= negative 0, = neutral, 1= positive

7.4.1 Actors' Involvement and Effectiveness in the Innovation System

The number of actors recognised as being involved in each project by more than half of the respondents was calculated. The average number of actors involved in a project that had <0.5 membership in the innovation outcome set was 3.15 whereas 4.75 actors were involved in projects that had >0.5 membership in the innovation outcome set. This difference in the average number of actors involved in projects with an innovation outcome are unlikely to occur by chance (t-test, p<0.001).

Five actors were recognised by more than half the respondents as being involved in the projects they assessed (Researchers, Industry firms, Industry associations, the Intermediary, and Government). Respondents also indicated whether (by presence or absence) the actor was effective in the conduct of the project (Table 7.1). Three of these five (Researchers, Industry firms and Intermediary) were assessed by more than half the respondents as being effective in the projects they assessed.

The involvement scores (Table 7.2) of Industry associations, Government and Intermediary were significantly higher (t-test, p<0.05) for projects with >0.5 membership of the innovation outcome set than those with <0.5 membership. The effectiveness scores (Table 7.2) of Industry firms, Industry associations, Intermediary and Government were significantly higher (t-test, p<0.05) for projects with >0.5 membership of the innovation outcome set than for those with <0.5 membership. The Involvement and Effectiveness of researchers was consistently very high in all cases, which results in insignificant differences between projects with high and low membership of the innovation outcome set.

Table 7.2 Involvement and Effectiveness scores for projects with high and low membership of the innovation outcome set

Actor	Involvement			Effectiveness		
	~INNOV*	INNOV	p	~INNOV	INNOV	p
Researcher	1.00	0.99	0.32	0.98	0.99	0.51
Industry firm	0.75	0.86	0.10	0.56	0.77	0.01
Industry association	0.37	0.70	<0.001	0.20	0.57	<0.001
Intermediary	0.86	0.97	0.03	0.76	0.90	0.02
Government	0.28	0.59	<0.001	0.15	0.48	<0.001
Supplier	0.23	0.44	0.009	0.15	0.36	0.006
Customer	0.04	0.21	<0.001	0.04	0.12	0.19
Entrepreneur	0.35	0.43	0.36	0.28	0.41	0.15

* ~ INNOV means < 0.5 membership of the innovation outcome set
INNOV means > 0.5 membership of the innovation outcome set

7.4.2 Network of actors in the innovation system

The perception of each actor's involvement and effectiveness can be considered from the point of view of each of the other actors. The actors' perceptions of the other actors can be presented as a network of Involvement and Effectiveness within this innovation system (Figure 7.1). The researcher and intermediary have central roles in an effective innovation system.

The nodes (circles) representing the actors represent the Involvement of the actor, while the edges (lines) represent the Effectiveness as perceived by each of the other actors. The Researchers, Industry firms, Industry association and Intermediary have a central position in the innovation system - both in terms of perceived Involvement and wide positive assessment of their Effectiveness. The Researchers, and the Intermediary, are assessed by the largest number of other actors as being highly Effective in this innovation system. Industry firms and Industry association(s) were perceived as Effective by other actors less often than Researchers and the Intermediary. Industry firms recognised its Association(s) as well as Researchers and Intermediary as Effective in the innovation system. The Government actor was less often perceived as being Involved, and not perceived as being Effective in the innovation system. The other actors were peripheral in this innovation system, both in terms of Involvement and Effectiveness. Other than the mutual recognition of Effectiveness between Researchers and Intermediary, there is no equally strong bidirectional recognition of Effectiveness. In network terms, there are several holes, in which the Effectiveness of an actor is not perceived by some of the other actors, but is perceived by others. It is suggested that the contributions of many actors only become available to the network through certain other actors. The key actors influencing the performance of the innovation system, according to the perceptions of the actors in the network, judged by their Involvement, Effectiveness, and mutual recognition, are the Researcher and the Intermediary.

7.4.3 Actors necessary for an innovation outcome

The respondents' assessments of Involvement or Effectiveness of the actors was analysed to determine whether they are necessary for an innovation outcome. Necessity is a set relationship in which the condition is necessary for an outcome, and will always be present when the outcome occurs. In QCA, consistency is a measure of the degree to which evidence supports the notion that a set relationship exists. It is possible that a condition may appear necessary for the outcome, but the relationship can be trivial rather than relevant, either because the condition set is so large that it is easy for the outcome to coincide with this set or because the condition can be essentially constant (Schneider & Wagemann 2012). The necessity of Involvement and Effectiveness of each of the five major actors was assessed (Table 7.3).

Schneider and Wagemann (2012) recommend that a consistency threshold of 0.9 be applied to claim necessity, which identifies the researchers' and intermediary's Involvement and Effectiveness to be necessary for an innovation outcome. Industry firms almost meet this criterion. However, by an additional criterion suggested by Schneider and Wagemann, these results are considered to be a trivial one because the relevance parameter is low for these actors. There is no established criterion for accepting a relationship as non-trivial based on the relevance parameter, however, 0.5 is not considered to be acceptable. The major reason for the low relevance for the researcher and intermediary is that they were perceived to be Involved and Effective in a very large proportion of cases, and thus have high membership both in cases with and without high membership of the innovation outcome set.

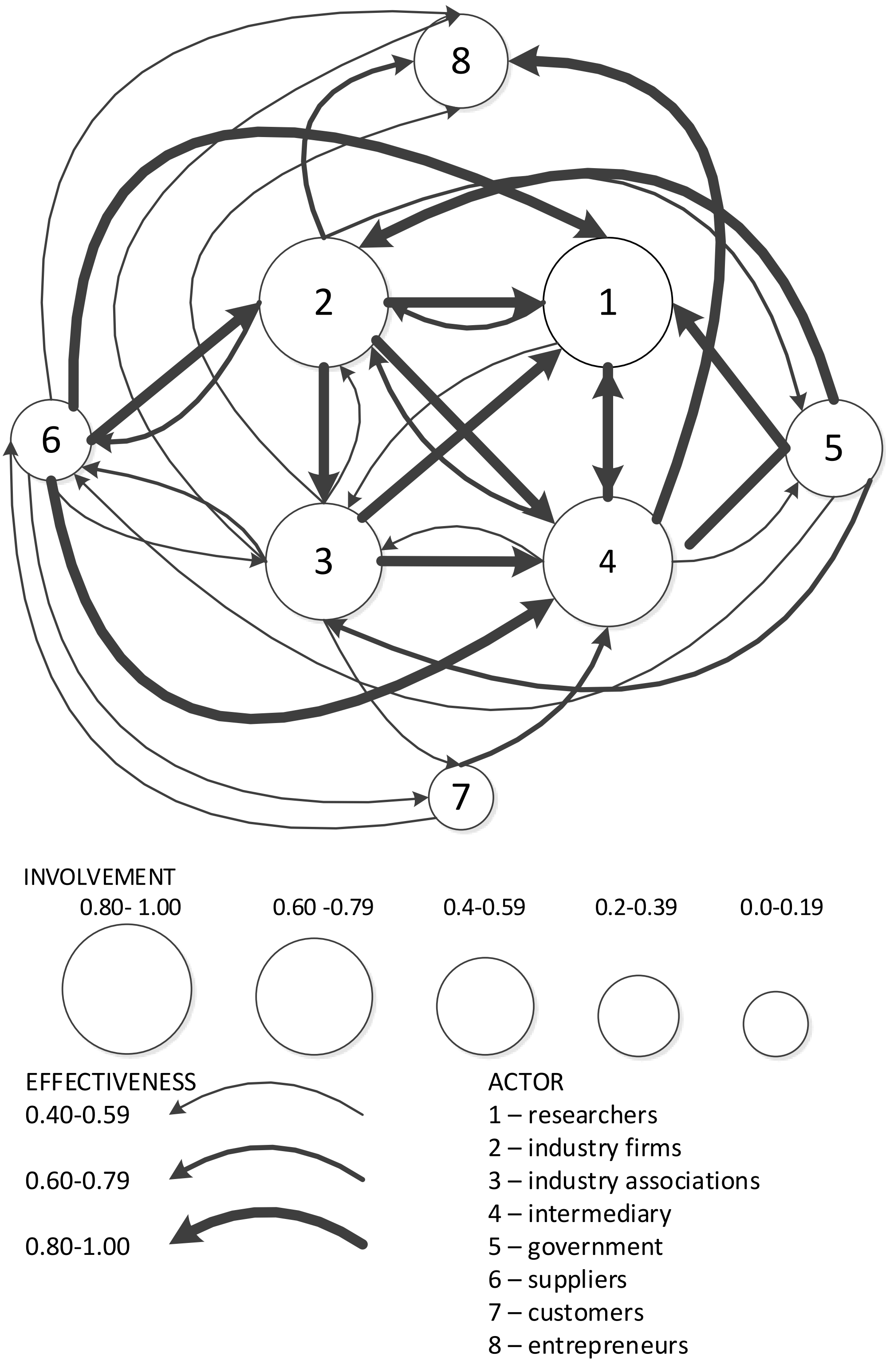


Figure 7.1 Actor involvement (as assessed by all respondents) and effectiveness of their involvement (assessed by each actor group).
The size of the circles represent the Involvement of the actors and the thickness of the lines represent the Effectiveness of the actors (head of arrow) as perceived by the others (tail of arrow).

Table 7.3 The necessity of Involvement and Effectiveness of actors for membership in the innovation outcome set

Actor	Involvement		Effectiveness		Both Involvement and Effectiveness	
	consistency	relevance	consistency	relevance	consistency	relevance
Researcher	1.00	0.03	1.00	0.05	1.00	0.09
Industry firm	0.89	0.51	0.73	0.84	0.72	0.85
Industry association	0.71	0.87	0.40	0.97	0.40	0.97
Intermediary	0.97	0.17	0.90	0.52	0.90	0.54
Government	0.60	0.89	0.30	0.96	0.30	0.96

7.4.4 Combination of actors leading to innovation

Given the significance of the Involvement and Effectiveness of the five major actors in this innovation system, we examined the combination of actors whose involvement or effectiveness may be sufficient for innovation to result.

7.4.4.1 Involvement of actors

Three configurations of actors' Involvement were found to lead to an innovation outcome (Table 7.4). The first two configurations of conditions provide a lot of explanation (raw coverage) of the outcome. The Involvement of Researchers and the Intermediary with either the Industry (firms or association) or Government are sufficient for an innovation outcome. Interestingly, the third configuration omitting the Industry association and Government, substituting Industry firms and being ambivalent about the Intermediary also results in projects where innovation set membership is >0.5. There are some cases where innovation may still occur without a high level of Involvement of all of the major actors. The model (three configurations) provides acceptable coverage and consistency of, and with, the data.

It is also necessary to look at the configurations of actor Involvement that led to lack of innovation outcomes. The coverage of this solution is low because a number of inconsistent outcomes from many configurations of actors. The lack of Involvement from Industry associations and/or firms is associated with lack of innovation outcome. The lack of Government Involvement can also lead to lack of innovation. The Involvement of the Intermediary is frequently associated with an innovation outcome, though lack of innovation is not prevented by Involvement. Industry (firms or association) involvement appears highly associated with an innovation outcome.

Table 7.4 Involvement of actors in projects leading to membership of the innovation outcome set.
fsQCA derived solution for the sufficiency of the condition, Involvement of the major actors, to explain the outcome, Innovation, and the negation of Involvement of the major actors, to explain a negation of Innovation.

Condition (actors)	Configurations for INNOV			Configurations for ~INNOV	
Researchers	+	+	+	+	+
Industry firms	0	0	+	~	0
Industry associations	+	0	~	0	~
Intermediary	+	+	0	+	+
Government	0	+	~	~	+
Raw coverage	0.71	0.59	0.29	0.34	0.35
Solution coverage		0.91		0.60	
Solution consistency		0.82		0.70	

INNOV means > 0.5 membership of the innovation outcome set, ~ INNOV means < 0.5 membership of the innovation outcome set. + means inclusion, ~ means the inclusion of the negation, 0 indifference to inclusion, of the condition in the outcome

7.4.4.2 Effectiveness of actors

The model to identify the actors whose effectiveness results in an innovation outcome has acceptable consistency and good coverage. Due to the nature of the innovation system under study, Researchers' Effectiveness is always part of the solution and the Intermediary's Effectiveness is frequently part of the solution. Industry firms' Effectiveness is often part of the solution, but Industry association and Government Effectiveness less often produce an innovation outcome. The Industry firms and Association appear to substitute for each other in many cases. Government Effectiveness is not often part of a solution.

Table 7.5 Effectiveness of actors in projects leading to membership of the innovation outcome set.
fsQCA derived solution for the sufficiency of the condition, Effectiveness of the major actors, to explain the outcome, Innovation, and the negation of Effectiveness of the major actors, to explain a negation of Innovation.

Condition (actors)	Configurations for INNOV			Configurations for ~INNOV	
Researchers	+	+	+	+	~
Industry firms	0	+	+	~	~
Industry associations	0	0	~	~	~
Intermediary	+	+	0	~	+
Government	~	0	~	~	~
Raw coverage	0.62	0.68	0.35	0.36	0.05
Solution coverage		0.92		0.40	
Solution consistency		0.79		0.76	

INNOV means > 0.5 membership of the innovation outcome set, ~ INNOV means < 0.5 membership of the innovation outcome set. + means inclusion, ~ means the inclusion of the negation, 0 indifference to inclusion, of the condition in the outcome

7.4.5 The role of the actors in preventing system weakness

Previous analysis (Chapter 5) demonstrated that, in this innovation system, certain conditions, were recurrently weak, resulting in poor innovation system performance and some projects having low membership of the innovation set. These innovation system conditions, specified by sectoral and TIS failure theories, must be met to achieve innovation system performance (Chapter 4). The actors' perceived behaviour in projects was investigated to determine if certain actors' Involvement or Effectiveness was responsible for strong innovation system conditions using fsQCA. No actors' membership of Involvement or Effectiveness sets was found to be necessary, by the criteria of consistency and relevance (Table 7.6), for membership of any tested condition set, previously identified as recurrently weak and leading to innovation system performance. However, a number of actors' memberships of the Involvement and/or Effectiveness sets were consistent with sufficiency for membership of the condition sets of interactions between innovation system actors, market failure, and direction of the search. There was no significant association between the actors and the condition of knowledge development. FsQCA was used to determine the combination(s) of actors that could result in the innovation system condition being strong enough to ensure innovation system performance.

Table 7.6 Goodness of fit parameters for the necessity of major actor involvement or effectiveness for a project to have >0.5 membership of a condition required for innovation system performance

Condition for Innovation System Performance	Network Condition	Goodness of fit parameter	Actor				
			Researchers	Industry firms	Industry associations	Intermediary	Government
Interaction	Involvement	consistency*	1.00	0.84	0.66	0.97	0.58
		relevance	0.03	0.45	0.80	0.17	0.87
		coverage**	0.69	0.71	0.80	0.70	0.83
	Effectiveness	consistency	0.99	0.65	0.36	0.86	0.31
		relevance	0.05	0.75	0.93	0.47	0.95
		coverage	0.69	0.76	0.82	0.72	0.85
Market	Involvement	consistency	1.00	0.87	0.64	0.97	0.55
		relevance	0.04	0.58	0.86	0.22	0.90
		coverage	0.77	0.82	0.87	0.79	0.88
	Effectiveness	consistency	0.99	0.67	0.36	0.87	0.29
		relevance	0.07	0.85	0.97	0.59	0.97
		coverage	0.77	0.88	0.93	0.83	0.89
Knowledge Development	Involvement	consistency	0.03	0.03	0.03	0.03	0.01
		relevance	0.03	0.42	0.76	0.15	0.80
		coverage	0.64	0.67	0.76	0.65	0.72
	Effectiveness	consistency	0.03	0.03	0.01	0.03	0.01
		relevance	0.04	0.72	0.92	0.44	0.93
		coverage	0.64	0.72	0.79	0.68	0.78
Direction	Involvement	consistency	1.00	0.87	0.69	0.98	0.58
		relevance	0.04	0.52	0.87	0.20	0.90
		coverage	0.73	0.78	0.89	0.75	0.89
	Effectiveness	consistency	0.99	0.67	0.39	0.90	0.30
		relevance	0.06	0.81	0.98	0.56	0.96
		coverage	0.73	0.83	0.94	0.81	0.89

* consistency of necessity and coverage of sufficiency have the same value
** coverage of necessity and consistency of sufficiency have the same value

The Involvement of Researcher and Intermediary was a moderately good fit for achievement of strong Interaction (Table 7.7). A larger, and more varied, group of actors' Effectiveness is required to achieve strong interactions. Inclusion of Industry associations is helpful, though sometimes, exclusion of the Industry associations may still result in interaction. Exclusion of the Government from a project may also still result in strong interaction. No configurations of actors, or lack of actors, were sufficient to result in lack of interaction.

Table 7.7 Involvement and Effectiveness of actors in projects leading to membership of the Interaction condition set.
fsQCA derived solution for the sufficiency of Involvement and Effectiveness of the major actors, to explain membership of the Interaction condition set.

Condition (actors)	Configurations of Involvement	Configurations of Effectiveness		
Researchers	+	+	+	+
Industry firms	0	+	0	0
Industry associations	0	0	0	~
Intermediary	+	+	+	+
Government	0	0	~	0
Raw coverage	0.97	0.62	0.62	0.55
Solution coverage	0.97	0.96		
Solution consistency	0.70	0.72		

+ means inclusion, ~ means the inclusion of the negation, 0 indifference to inclusion, of the condition in the outcome

The Involvement of a large number of actors favored membership of the market condition set but there were no actors, other than Researchers and Intermediary frequently involved contributing to a solution highly consistent with the data (Table 7.8). The five configurations of actors' Effectiveness for achieving membership of the market condition varied widely though the solution provides good consistency with the data. Again, there were no configurations of actors providing consistent association with lack of strong market.

Table 7.8 Involvement and Effectiveness of actors in projects leading to membership of the Market condition set.
fsQCA derived solution for the sufficiency of Involvement and Effectiveness of the major actors, to explain membership of the Interaction condition set.

Condition (actors)	Configurations of Involvement			Configurations of Effectiveness				
Researchers	+	+	+	+	+	+	+	0
Industry firms	0	0	+	0	0	0	0	+
Industry associations	+	0	~	0	~	0	~	~
Intermediary	+	+	0	+	0	+	+	+
Government	0	+	~	0	~	~	0	~
Raw coverage	0.64	0.54	0.31	0.63	0.61	0.62	0.55	0.26
Solution coverage		0.86				0.99		
Solution consistency		0.85				0.79		

+ means inclusion, ~ means the inclusion of the negation, 0 indifference to inclusion, of the condition in the outcome

A high number of actors' Involvement in projects is associated with strong direction of the search (Table 7.9). Industry firms, their association or government involvement may all substitute for one another, intermediary involvement is needed to produce a solution with good consistency. The effectiveness of actors follows much the same configurations as for Involvement with intermediary always Effective and industry associations and Government sometimes being weakly effective to produce a consistent result. Weak actor involvement and effectiveness did not produce results which effectively covered the weakness of direction (results not shown).

7.5 Discussion

The work described here is a multiple case study of a single innovation system (food safety in the Australian red meat industry), at the intersection of sectoral and technological systems. While the results apply only to this particular innovation system, many of the features explored may apply generally to other innovation systems, especially those with similar features. Some relevant features of this innovation system are the highly regulated industry with socialised funding for industry innovation and an intermediary organisation created by joint agreement of government and industry with industry innovation as a key purpose.

Table 7.9 Involvement and Effectiveness of actors in projects leading to membership of the Direction condition set.
fsQCA derived solution for the sufficiency of Involvement and Effectiveness of the major actors, to explain membership of the Interaction condition set.

Condition (actors)	Configurations of Involvement			Configurations of Effectiveness		
Researchers	+	+	+	+	+	+
Industry firms	+	0	0	0	0	+
Industry associations	0	+	0	0	~	0
Intermediary	+	+	+	+	+	+
Government	0	0	+	~	0	0
Raw coverage	0.86	0.69	0.58	0.64	0.56	0.64
Solution coverage		0.92			0.89	
Solution consistency		0.79			0.82	

+ means inclusion, ~ means the inclusion of the negation, 0 indifference to inclusion, of the condition in the outcome

Through this study, conducted at the level of projects, the operation of the actor-oriented elements of innovation system frameworks is examined. Statistical analysis of the association between the number of actors, their involvement and effectiveness and innovation system performance is supported by QCA that makes claims, through the application of set theory, to the analysis of causality expressed as a causal pathway (Berg-Schlosser et al. 2009) or recipe (Ordanini, Parasuraman & Rubera 2014). QCA is used to examine the configurations of actors that may lead to innovation system performance as well as the configurations of actors that may lead to the strength or weakness of innovation system elements whose strength is known to vary in this innovation system. Network analysis is used to delineate the relationships between actors.

This work contributes to innovation systems theory and has implications for both policy and practice.

7.5.1 Contribution to theory

Analysis of this innovation system at the project level demonstrates that the involvement of a sufficient number of suitable actors, and the effectiveness of those actors, leads to the innovation system performance required for innovation.

On average, projects with innovation outcomes have more actors involved than those without an innovation outcome. In this system, the recognised involvement of Industry associations, Government and the Intermediary were significantly greater in projects with innovation outcomes, and in addition to these actors, the perceived effectiveness of Industry firms and Suppliers were significantly greater in projects with an innovation outcome.

The need to have more actors effectively involved in projects to ensure innovation system performance may be explained by the network of those actors. The network analysis shows that actors whose involvement and effectiveness contribute most often to innovation system performance don't uniformly recognise each other's contributions. An actor's contribution may be acknowledged only by a few other actors. The open network structure points to the significance of the actors that ensure the resources of the less embedded actors become available to the remainder of the network and to the project. The researcher and intermediary were central in this network and may serve this role.

Turning to the conditions required for innovation system performance, no actor's Involvement or Effectiveness was necessary for achievement of high membership in one of the innovation system condition sets: interaction, markets, or direction. Multiple configurations of actors may be sufficient for innovation outcome set membership. Involvement of at least three of the five major actors and variable involvement of the other two are found in cases that account for the majority of the innovation outcome set membership. It is possible that different projects will need different actors and different actions by those actors to ensure innovation system performance. Cases without an innovation outcome may be explained frequently by the absence of Industry firms and Government, or by the absence of Industry associations, though causes other than actor involvement are implicated through innovation system frameworks.

Intermediaries may be a significant actor in ensuring innovation system performance by linking the IS actors with each other and critically to the market. The intermediary was seen to be highly involved and effective in a high proportion of cases and significantly more Involved and Effective in cases with an innovation outcome. The Intermediary's Effectiveness was necessary with moderate relevance to the innovation system conditions of interaction, market and direction. Researchers were also seen as involved and effective by almost every survey respondent, reflecting the highly knowledge intensive nature of food safety (Desmarchelier & Szabo 2008) but the goodness of fit parameters for the significance of their Involvement and Effectiveness was at least a little less than those of the Intermediary.

We suggest that effectiveness of actors in the innovation system is determined by their contribution to the strength of innovation system conditions, either through their own effort in effectively applying resources to the innovation system or acting as a conduit for the contribution of others, thus ensuring innovation system performance. In this system the focus is on the intermediary, but this role may not be distinct, or may be shared in other innovation systems.

Theory could be further developed by understanding the relationship between the effective involvement of various innovation system actors and the strength of innovation system elements. The intermediation role needs to be understood in the context of innovation system elements applied at the project level.

7.5.2 Implication for policy

Prior to the “dismantling of the extension service and regional applied research stations” in nationally important innovation systems such as agriculture many of the functions of innovation systems were supported by the public (see for example, Klerkx and Leeuwis (2008b p. 264). In addition, innovation systems approaches have had a significant impact on the development of innovation policy, but little attention has been given to how these approaches can be applied at the level of projects. Innovation policy needs to be focused not only on systems level outcomes, but on the project level outcomes that are critical to economic competitiveness. Policy needs to explicitly take into account the important role of researchers and intermediaries in innovation success. For example, what are the policy implications and institutional support required to build capacity and performance in the innovation system? Likewise, what barriers can be removed to enhance efficient and effective network and knowledge brokering operations?

7.5.3 Implication for practice

This work adds weight to that already undertaken (Chapter 5) that sectoral and technological innovation systems frameworks can and should be applied at the level of projects, where innovation outcomes are desired. Within a single innovation system the effective involvement of actors varies, and is associated with poor innovation system performance. A focus of project managers should be to understand the role of intermediaries in innovation systems and make efforts to ensure adequate involvement of actors and their effect on operation of innovation systems to maximise innovation system performance. For example, in the case study's innovation system, the elements of interaction and direction of the search were frequently found to be weak and intermediaries have an obvious role and interest in ensuring that these elements are strengthened.

Weak interactions, identified as an element in the structural theory of innovation system failure (Klein Woolthuis, Lankhuizen & Gilsing 2005) is shown by this work to be complex, and thus requiring significant attention. The system studied has an intermediary with the capacity to employ sufficient resources to cause the innovation system to perform effectively most of the time. An important function of intermediaries is the formation and management of interactions (Dhanaraj and Parkhe, 2006), so these need to be managed at the project level, not least for ensuring that the interactions in the innovation system are effective.

When analysing this innovation system through the lens of the functional theory of innovation system failure (Bergek et al., 2008) direction of the search was found to be recurrently implicated in failures of projects to lead to innovation (Chapter 5). The function of 'direction of the search' relates to the motivation and incentives of actors to take particular direction, perhaps through articulation of demand by potential users and response by providers (Budde et al., 2012; Hekkert et al., 2007). Demand articulation is identified as an important role for intermediaries in innovation systems (Klerkx and Leeuwis, 2009).

7.6 Conclusion

The significance of actors' involvement for innovation system performance at the project level was explored. Projects with stronger innovation system performance had more actors effectively involved than projects with weaker performance. The interrelationship and network linkages between intermediaries, researchers, and firms in the industry are essential for projects that result in innovation. This finding supports the work of Howells (2006), Klerkx and Leeuwis (2008a,b, 2009) and Edler and Yeow (2016) with intermediaries serving as boundary spanners that match the needs of industry for innovation with the ability of researchers to supply it.

The present study suggests that intermediaries and the networks that they build and span are critically important to innovation system performance from both a policy and managerial perspective. At a policy level, there must be encouragement to involve and allow the contribution of all the relevant actors, driven by the boundary spanning capabilities of the intermediaries. This is particularly relevant in innovation systems that are highly regulated and dependent upon research. Likewise, at the project level, managers need to understand and leverage the functionality of innovation system intermediation to facilitate innovation outcomes.

This study provides a glimpse into the value of intermediaries to both technological and SIS performance at the project level. The authors hope that this study encourages additional research into the application of innovation systems at the project level. Likewise, the authors hope that the study stimulates work that helps better understand the role and value of intermediaries in innovation systems, from technological and sectoral perspectives.

8

Sectoral and technological innovation system failure frameworks: Application to project-level innovation practice[13]

8.1 Introduction

Innovation has long been seen by policy makers as a critical driver of regional and national competitiveness (Organisation for Economic Co-operation and Development 2010) and important for economic growth (Schwab 2015). Systematic approaches to understanding innovation have considered all the important economic, social, political, organisational, institutional, and other factors that influence the development, diffusion, and use of innovations (Edquist, Charles 1997) through an innovation systems (IS) approach. The IS approach can be described as a method of analysis of socio-technical systems that attempt to create innovation. The systems are bounded through codification of properties or characteristics which become both the focus of analysis and intervention. The IS approach has influenced innovation policy in many governments (Anonymous 2009; Cagnin, Amanatidou & Keenan 2012; Dodgson et al. 2011; Hoppmann, Huenteler & Girod 2014; Manjón & Merino 2012). Yet, the IS approach has had little impact at the practitioner level. Various IS actors, such as researchers, are charged with conceiving, planning, and implementing research and development projects that may lead

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to innovation. Yet their thinking is dominated by the linear model (Fagerberg 2005; Godin 2006) which justifies a narrow focus on the research phase, and assumes that filling ‘knowledge gaps’ automatically leads to innovation (Australia. Productivity Commission 2007, 2011). Institutionalised focus on measureable outputs such as scientific publications and patents (Organisation for Economic Co-operation and Development & Statistical Office of the European Communities 2005) is only gradually being augmented by attention to activities required to translate these outputs into meaningful innovation (Beerkens 2013; Casadevall & Fang 2014). Because the IS approach aims to be applicable to "explain—and perhaps influence—the processes of innovation" (Edquist, Charles 1997, p. 2), it should be able to link high level innovation policy to project level implementation.

IS failure has been investigated by many scholars and frameworks to explain and potentially predict failure to innovate have been proposed. These frameworks have been used at the policy level to create an environment in which innovation can occur, and to assess the strengths and weaknesses of developing technologies or sectoral regimes. To date they have not been applied at the project level where scientists, technologists, developers and entrepreneurs need tools to enhance the efficiency and effectiveness of the innovation process. The tendency of scholars to consider the innovation systems approaches as conceptual frameworks has resulted in conceptual ambiguity (Edquist, Charles 1997) and in approaches not being thoroughly tested or developed into tools to assist practitioners to manage innovation processes. Innovation scholars have usually worked with one innovation system approach or another, choosing to analyse a system through a sectoral or a technological systems lens, and infrequently utilizing multiple analytical approaches.

This paper attempts to contribute to the continuing innovation systems conversation in three major ways. First by focusing on IS using projects as the unit of analysis we demonstrate the application of IS to such projects. Second, by exploring how analysis at the project level may lead to both policy and management responses to solve innovation system weaknesses identified. Third, by combining sectoral and technological IS failure frameworks for project-level analysis.

This paper reviews the development of innovation system failure frameworks and considers how they can be applied at the level of individual research projects to increase innovation system performance (ISP) and therefore, the likelihood of an innovation outcome. The paper proceeds as follows: In section 2, the two innovation system approaches (sectoral and technological) are described and one IS failure framework from each approach is identified as containing a theoretical statement. Section 3 describes testing of those theories in an innovation system geared to low risk incremental innovation through applied research, facilitated by an intermediary organisation. Section 4 suggests how innovation systems theories can be consolidated and applied at policy and management levels to ensure that scarce resources are best applied to ensure that research leads to innovation.

8.2. Innovation systems

Innovation systems thinking had its genesis in the 1980s (Edquist, C 2005). The approach rose from dissatisfaction with the inadequacies of the 'market failure' argument with its simplistic assumption that firms act alone and neglect the role that institutions (such as legal systems, regulations, customs, norms and values that govern behaviour) play in enabling and constraining innovation (Bergek et al. 2010; Chaminade & Edquist 2010; Klein Woolthuis, Lankhuizen & Gilsing 2005). The approach taken to IS has been conceptual and used for analysis at a high level. . There are two approaches to IS that are applicable at the project level: sectoral and technological systems, and frameworks have been proposed for understanding innovation failure in these IS.

Both the SIS and TIS literatures offer the possibility of understanding how and why an IS may fail and a project conducting research and development may not lead to an innovation outcome. The terms "imperfection" (Klein Woolthuis, Lankhuizen & Gilsing 2005; van Mierlo et al. 2010), "weakness" (Jacobsson, S & Bergek 2011; van Alphen, Hekkert & Turkenburg 2009) and "problem" (Edquist, C 2011; Negro, Alkemade & Hekkert 2012) have been used along with "failure" (Edquist, C 2011; Klein Woolthuis, Lankhuizen & Gilsing 2005) to describe the state of IS elements that leads to lack of innovation system performance (ISP). The continuum from 'weakness' to 'strength' can usefully describe the status of system elements with respect to whether they sufficiently support ISP and therefore innovation outcomes. Two widely-recognised frameworks for diagnosing IS failure are drawn from SIS and TIS approaches.

Klein Woolthuis, Lankhuizen and Gilsing (2005) base their failure framework on the assumptions of SIS: that innovation does not occur in isolation, institutions are critical, and evolutionary processes play an important role in determining innovation outcomes. They argue that systemic weaknesses can undermine innovation, and seek to identify these, at the intersection of actors and the other system elements (which are referred to as "rules"). Because it considers systemic and institutional elements the SIS is sometimes referred to as a 'structural' approach (Bergek et al. 2008; Wieczorek & Hekkert 2012).

Based on a TIS approach, Bergek et al. (2008) failure framework claims that certain processes, or functions, are needed for innovation to occur. Their ‘functional approach’ also suggests that inducement or blocking mechanisms may encourage or hinder the innovation processes.

Both these frameworks for analysis and policy intervention are based on empirical studies and neither claim that a theory has been developed. Hunt (2010) defines theories as being systematically related statements that contain law-like generalisations that are able to be empirically tested. The frameworks of Klein Woolthuis and Bergek can be considered to contain theories based on Hunt (2010). Both claim to identify the weaknesses which prevent ISP necessary to achieve innovation outcomes. The structural theory's claim is that system failure will occur if system actors are not working effectively with system elements (rules) and therefore the learning and innovation by actors in the system may be constrained. The claim of the functional theory is that innovation depends on key processes, or functions, that directly influence the development, diffusion and use of a new technology and thus the performance of the innovation system. According to both theories, it is not possible for an innovation system with severe weaknesses to produce an innovation. These statements of theory have not been tested. These two theories are not oppositional; they may both be correct, as they do not suggest what is necessary for success, but rather an array of elements required to avoid failure, that may well overlap. They arise from different approaches and provide different perspectives. However, there is a value to both policy-makers and practitioners in knowing whether one is more useful than the other. In the next two sub-sections we detail these two frameworks as theories of IS failure in order that they can be evaluated in Sections 3 and 4.

8.2.1 Structural Failure Framework

The structural failure framework arises from the SIS approach. SIS are "composed of a set of new and established products for specific uses, and a set of agents carrying out activities and market and non-market interactions for the creation, production and sale of those products" (Malerba 2004, p. 16). SIS focus on firms involved in innovation activities and interactions between firms and a social, economic and policy environment that define an economic sector (Klein Woolthuis, Lankhuizen & Gilsing 2005). SIS are composed of actors, interactions of those actors, institutions and infrastructure (Edquist, C 2005; Klein Woolthuis, Lankhuizen & Gilsing 2005). Patterns of innovation and development differ across economic sectors (Malerba & Orsenigo 1997). Therefore a sectoral focus has sought to understand how innovation occurs within and between firms within a sector, rather than across an economy.

Klein Woolthuis, Lankhuizen and Gilsing (2005) based their framework on a review that empirically identified weaknesses in innovation systems; synthesizing of these weaknesses into a framework. For example, Carlsson and Jacobsson (1997) describe weaknesses of networking, institutions or systems (actors, regional or national systems), while Smith (1997) describes infrastructural and institutional weaknesses. Edquist et al. (1997) suggests institutional and interactional weaknesses. Klein Woolthuis, Lankhuizen and Gilsing (2005) consolidate the described weaknesses, and standardise their description in order to locate system weaknesses at the intersection of 'rules' and 'players' (or actors) which allow system weaknesses to be clearly defined in terms of the interactions of players with the system rules, and amenable to rational policy response.

In the first dimension, Klein Woolthuis, Lankhuizen and Gilsing (2005) defined various types of actors:

- demand (consumers, large buyers)
- companies (large firms, multi-national corporations, small to medium enterprises, start-up companies)
- knowledge institutes (universities, technology institutes)
- third parties (banks, venture capitalists, intermediaries, consultants, sector organisations employers).

In the second dimension, rules were categorised as:

- infrastructural (information and communication technology, energy supply, roads, railroads, telecommunications, scientific and applied knowledge and skills, testing facilities, possibilities for knowledge transfer, patents, training and education)
- institutional (hard: formal written consciously created, and soft: informal, spontaneous and unwritten 'rules of the game')
- interaction (weak network failure due to poor connectivity between actors, strong network failure, such as group of actors dominated by one partner, an internal orientation and failure to seek new approaches)
- capabilities of the actors (lack of competence capacity, or resources).

This framework has been adapted effectively to various contexts. These range from analyses of SIS in the Australian red meat (Pitt & Nelle 2008), Dutch agriculture (van Mierlo, Arkesteijn & Leeuwis 2010), Dutch healthcare (Janssen 2009), Dutch construction (Klein Woolthuis 2010), Chinese information and communication (Zhang & Liang 2012) and Greek sea-port (Arduino et al. 2013) sectors. In many of these applications authors suggest the framework is useful (Janssen 2009), comprehensive (Pitt & Nelle 2008), provides valuable insight (Janssen & Moors 2013), or allows identification of system weaknesses (Klerkx & Leeuwis 2009). van der Vlies and Felix (2013) found the framework useful for mapping drivers and barriers to technology transfer and helping to uncover the source of both successes and challenges in the developing telecare innovation system.

The categories and identity of actors has been added to by several authors, Klein Woolthuis (2010) acknowledge government (regulator, national, local) as a key actor group. Other actor groups include value chains (Pitt & Nelle 2008) and lead clients (Klein Woolthuis 2010) as demand creators, entrepreneurs and professionals who may act like companies (Janssen 2009), and trade unions who may be significant third parties (Pitt & Nelle 2008). Lamprinopoulou et al. (2014) adopted an actor typology in which all the players were grouped into four actor domains: research, enterprise, indirect demand/innovation influencers and intermediaries.

The list of possible weaknesses has been added to and redefined by several authors (reviewed by Negro et al. (2012)). Pitt and Nelle (2008) identify three kinds of adaptive weakness within IS: lock-in, internal orientation myopia and transition. Lock-in problems were dismissed by Klein Woolthuis, Lankhuizen and Gilsing (2005) and Negro, Alkemade and Hekkert (2012) as the result of other identified system weaknesses, such as strong or weak network weakness or a capability weakness. Similarly, myopia is seen to be a type of strong network weakness in which insufficient attention is paid to development outside the network (Klein Woolthuis, Lankhuizen & Gilsing 2005). Transition weakness could be due to a weakness in any of the other elements. Therefore, all of these adaptive weaknesses may be considered as indicators or symptoms of other system weaknesses. Pitt and Nelle (2008) also identify 'sector culture failure' which they characterise as lack of entrepreneurial orientation, inability to enter a new technological domain and lack of support for innovative start-ups. These problems may be soft institutional or capability problems. Market failure, in terms of demand and structure of markets, have been specifically restored to the framework (Klein Woolthuis 2010; van Mierlo et al. 2010; Weber & Rohracher 2012).

The structural framework has also been developed to increase its ability to provide direction for practice change and intervention. Pitt and Nelle (2008) add 'dimensions' to each area of weakness, suggesting evidence for each area. This level of detail is a step towards clear criteria for the diagnosis of system weaknesses. The use of 'system instruments' that are interventions to address the system weakness have been proposed (van Mierlo et al. 2010; Wieczorek & Hekkert 2012). Suggestions have been made to include a temporal dimension to system analysis so that the analysis can adequately respond to stages of development (Arduino et al. 2013). The analysis has been further extended by considering the positive and negative aspects of actor performance and the type of innovation being sought (technological, managerial or cultural) (Roumboutsos, Kapros & Vanelslander 2014). None of these suggestions have provided a comprehensive tool to using the framework for innovation project management.

The structural framework has been critiqued for lack of definition, detail and policy tools. It has also been criticised for the lack of diagnostic indicators of system failure and system weaknesses (Bergek et al. 2008; Wieczorek & Hekkert 2012). The framework has also been criticised for not encompassing the detail within an innovation system such as the possible multiple roles of some organisations or the ability of actors to have a positive or negative influence on system dynamics (Bergek et al. 2008; Dantas 2011; Hellsmark & Jacobsson 2009) . These criticisms have led some scholars to suggest that this framework fails to explain system operation and performance (Chaminade & Edquist 2006, 2010; Dantas 2011). Such deficiencies result in low capacity to identify policy instruments or interventions to correct the identified weaknesses (Wieczorek & Hekkert 2012).

8.2.2 Functional Failure Framework

The functional failure framework arises from the TIS approach. TIS may be defined, generally, as a "network of agents interacting in the economic/industrial area ... involved in the generation, diffusion, and utilization of technology" (Carlsson & Stankiewicz 1991, p. 94). Bergek et al. (2008) define a TIS as containing all the elements necessary to influence the innovation process for a particular technology, identified as actors, their networks, and institutions (Jacobsson, T & Jacobsson 2014). Through these elements technological systems are viewed as platforms that cluster resources within a favourable institutional infrastructure and enable competent firms to develop and exploit opportunities (Carlsson & Stankiewicz 1991).

The framework of Bergek et al. (2008) draws on an understanding of entrepreneurs operating in a socially constructed systems (van de Ven 1993), coalitions advocating for change (Sabatier, PA 1998), strategic niche management (Kemp, Schot & Hoogma 1998), and previous work investigating functions in TIS (Bergek et al. 2010; Hekkert et al. 2007). Liu et al. (2015)

bibliometric analysis suggests that this framework is a turning point in innovation studies. The structural components of the TIS (actors, networks, institutions) receive little attention from scholars with attention being directed to the key processes or ‘functions’ operating within TIS (Table 1). The functions, defined slightly differently by different scholars, are considered to be characteristic of the TIS rather than being linked to a particular actor, and the functional pattern can then be assessed, the factors ‘inducing’ or ‘blocking’ the system can be diagnosed, leading to the identification of policy problems and interventions.

Like the structure framework, the functional weakness framework has been applied to analyse numerous contexts. These range across transport in Netherlands (Farla, Alkemade & Suurs 2010), microgeneration of electricity in the United Kingdom and Germany (Praetorius et al. 2010), combined-heat-and-power systems in the United Kingdom (Hudson, Winskel & Allen 2011), renewable electricity technologies (del Río & Bleda 2012), sustainable energy systems in United Arab Emirates and Saudi Arabia (Al-Saleh & Vidican 2013; Vidican et al. 2012), and Chinese wind power (Gosens & Lu 2013). Various authors have noted that this approach is useful for technological policy research (Coenen & Díaz López 2010), explicit conceptualisation of actors' strategies (Truffer & Coenen 2012) and, allowing a comprehensive analysis of multiple influences (Aláez et al. 2008). A functional failure analysis has also been used to (Gabaldón-Estevan & Hekkert 2013) analyse a sectoral system, claiming it to be flexible and useful Apart from retrospective analyses, some have promoted the combination of functional analysis and participatory stakeholder dialogue to assist in framing public debate (Breukers et al. 2014).

A number of scholars have contributed to this framework. Bleda and Del Río (2013) and Weber and Rohracher (2012) added market failure categories to complement the functional weaknesses. Cagnin et al (2012) omitted the legitimization function and provided additional insight into the definition of functions (Table 8.1); while, McDowell et al. (2013) points out that functional weaknesses need to be examined not only in the formative and growth phases, but critically in the transfer phase of a technology. The application of the framework was further developed by the identification of events (Suurs & Hekkert 2009) and diagnostic questions (Wieczorek & Hekkert 2012) that may indicate the strength of functions . Lamprinopoulou et al. (2014) consider separately the provision of funds from mobilising of other (in kind and human) resources. Al-Saleh and Vidican (2013) conceptualised a "force field" analysis to present the action of inducement and blocking mechanisms for system functions. Walrave and Raven (2016) have considered how the multi-level perspective can inform the TIS functions and have investigated, through modelling, the functions that may be the "motors of innovation".

Table 8.1 Functions of a technological innovation system as defined by various scholars.

Hekkert et al. (2007)	Bergek et al. (2008)	Cagnin, Amanatidou and Keenan (2012)
Knowledge development - R&D and knowledge development are prerequisites with the innovation system - 'learning by searching' and 'learning by doing'	**Knowledge development and diffusion** - the knowledge base, its evolution, and how knowledge is diffused and combined in the system	**Nurture knowledge development** - research and development, knowledge of production design and markets
Knowledge diffusion through networks - exchange of information, especially between R&D and government competitors and market		**Promote knowledge diffusion** - mediated through networks, supply chains, standards
Guidance of the search - choices are made from various technological options for further investment, involving industry, government, markets	**Influence on the direction of search** - the incentive and/or pressures for organisation to choose to enter the TIS and mechanisms having influence of the search within the TIS	**Guide direction of the search and selection** - guiding actors to select options for investment through visions, expectations, regulations, policy, activities of lead users
Entrepreneurial activities - turning the potential of new knowledge, networks, and markets into concrete actions to generate - and take advantage of - new business opportunities	**Entrepreneurial experimentation** - investigation of new technologies and applications in an attempt to overcome the uncertainties that exist within a TIS	**Facilitate experimentation and learning** - entrepreneurial experimentation, generating variety, social learning
Market formation -regulation and formation of markets that will allow new developing technologies to continue to develop	**Market formation** - the development of a market through capability to, and actual articulation of demand, price/performance, reduction of uncertainties	**Promote market formation** - create spaces through policies, standards or regulations that nurture demand for innovations
Creation of legitimacy / counteract resistance to change - becoming part of an incumbent regime or overthrowing it; development of advocacy coalitions for processes of change	**Legitimation** - social acceptance by relevant actors	
Resources mobilization - Supply of resources, both financial and human capital for innovation	**Resource mobilization** - the ability of the TIS to provide competence/human capital, financial capital and complementary products, service and network infrastructure	**Develop and mobilise resources** - human resources, capital, infrastructure
	Development of positive externalities - entry of new firms may resolve uncertainties, about technologies and markets, may legitimate the TIS either directly or through strengthening the power of advocacy coalitions and may allow new combinations to arise	

The TIS failure framework has been critiqued by a number of scholars. A recent article by three experienced TIS scholars reviews and responds to criticisms of the TIS functional failure approach (Markard, Hekkert & Jacobsson 2015). The criticisms most related to innovation at the project level are how the TIS approach deals with context, delineation of the system, spatial aspects and policy recommendations. The context of the TIS refers to the environment beyond the boundaries defined for the TIS. Some contextual aspects include, the dynamic nature of the economy and technologies outside the TIS (Hillman & Sandén 2008) and the position of the TIS within a developing market and policy domain (Lai et al. 2012). In dealing with the criticism of how the TIS approach addresses the context of the TIS, Bergek et al. (2015) admits that consideration of the interactions of the TIS with structures and relevant factors of a technological, sectoral, geographical and political nature could be strengthened. The need to explicitly consider the capabilities and roles of actors, networks and institutions has also been identified as a limitation of most TIS analyses (Hudson, Winskel & Allen 2011; Wieczorek & Hekkert 2012). The TIS approach has been criticised for not defining a geographical boundary when considering technologies and thereby not considering the differences that may arise between countries in the way that a technology is developed and used (del Río & Bleda 2012; Hillman et al. 2008; Truffer & Coenen 2012). Schmidt and Dabur (2014) have explicitly added the role of national borders (effect of national institutions) and international technology transfer to their functional analysis of TIS. National innovation policy can have an effect on the conduct of projects. Lastly, analysis of the TIS using the functional approach has been criticised for the broad policy recommendations made that are neither specific nor substantiated, which relates more to practice than to a flaw in the approach.

8.2.3 Combining Structural and Functional Failure Frameworks

An innovation can be located at the intersection of national, sectoral and technological innovation systems that may overlap in various ways (Hekkert et al. 2007). For example, Markard and Truffer (2008) describe the overlap of technological, sectoral and national innovation systems using the example of fuel cell technology, which has applications in several different industry sectors and different countries, which may lead to different trajectories of innovation and development. Little scholarship has been devoted to considering how IS failure frameworks can be reconciled or combined.

In particular, a tension appears to exist among TIS scholars regarding the relevance of SIS approaches, and the merits of broadening the considerations within the functional weakness framework that might incorporate an understanding of sectoral failure. For example, (Markard, Hekkert & Jacobsson 2015, p. 78) argue that analysis of a TIS "takes into account both endogenous and exogenous structural elements that influence the dynamics of the system" whereas Bergek et al. (2015) note that understanding of the interactions of the TIS functions with the structural elements could be strengthened.

Wieczorek and Hekkert (2012) address the issue most specifically and suggest that functional analysis alone is incomplete and that that the frameworks of Klein Woolthuis and Bergek can be combined, since they have the same scholarly foundation. An example of this suggestion was highlighted by Vidican et al. (2012), studying the emerging solar energy sector in the United Arab Emirates. They argued that, when investigating the emergence of new industries, it is necessary to consider the multiple knowledge and technological bases that contribute to the development of a sector, rather than taking a functional failures approach exclusively. Further, Lamprinopoulou et al. (2014) developed an integrated framework to compare two national agricultural innovation systems of the Netherlands and Scotland, and argued that an integrated framework provided a more holistic perspective.

Despite claims about the potential usefulness of combined structural and functional weakness frameworks no evaluation has been made of combined frameworks for analysis of projects at the intersection of sectoral and technological innovation systems.

8.3. Evaluating innovation system failure theories

Project level research and development may occur within the boundaries of sectoral and technological IS. Projects can be assessed for their innovation success just as the strength of system elements can be evaluated using the structural and functional frameworks. It is thus possible to test whether IS weaknesses are associated with poor ISP according to each of the structural and functional theories.

A study of the IS at the intersection of technological (food safety) and sectoral (red meat industry) IS in Australia, retrospectively assessed the strength of IS elements defined by both the structural and functional theories, as well as innovation outcomes (Chapters 4 and 5). These studies have progressed in two stages:

1. testing the applicability of structural and functional weakness theories to ISP
2. examining the IS for weaknesses that lead to lack of ISP.

A multiple case study approach defined cases (n=41) as projects in which some change (innovation) was expected at the commencement of the research. Data were collected for all projects meeting the case definition through an on-line survey of people who had some involvement in, or knowledge of, each project (Chapter 4). The data consisted of Likert-scale responses to statements corresponding to elements of both structural and functional theories of ISP and innovation outcome.

FsQCA methods were applied (Rihoux and Ragin, 2009; Schneider and Wagemann, 2010; 2012) in which the necessity or sufficiency of an antecedent condition, or set of conditions, for the causation of an outcome are determined. QCA methods are consistent with case study methodology, and are suitable for small to medium numbers of cases. Comparison of the cases occurs through the application of fuzzy-set theory, in which data are calibrated as to the degree with which the data is within the set (Berg-Schlosser et al. 2009). The method provides rigorous testing of propositions without relying on correlations between and inputs and the net effect of parameters on outcomes (Woodside 2013) or on regression analysis (Armstrong 2012).

QCA allows the testing of the proposition that all elements of the innovation system need to be strong in order to achieve ISP. The diversity of the data collected was limited because some conditions were strong in all cases meaning the theory cannot be thoroughly tested. However, through fsQCA, all conditions of both the structural and functional theories were collectively present where an innovation outcome was perceived to have occurred by respondents (n=32). The standard QCA goodness of fit parameters support the proposition that all of the conditions of each theory are necessary for an innovation outcome. The goodness of fit parameters also support that the conditions are sufficient to explain the innovation outcome (Chapter 4).

Cases with conditions that were identified as being weak, corresponded with lack of ISP (lack of certain innovation outcome) (n=9). Using more stringent calibration of fuzzy-set membership, thus identifying conditions required to be strong for a high certainty of ISP, some conditions were found to be recurrently weak (Chapter 5). Of the structural conditions, interactions between system actors were frequently seen by participants as being weak. Likewise, the weakness of market conditions was linked to poor ISP across many cases in this study. Market failure has been recognised as an issue in food safety improvement (Caswell, 1998). Compared to structural conditions, the functional theory identified a larger number of weak conditions and a larger number of alternate combinations of conditions leading to lack of ISP. However, the only conditions consistently associated either alone or in combination, were 'guidance of the search' and 'knowledge development'. The question of which IS functions drive ISP remains contextual. Guidance of the search, entrepreneurial activities and legitimation are seen as typical drivers of IS development (Hekkert et al., 2007) and are significant at different stages of technology development (Suurs & Hekkert, 2009; Suurs et al., 2009). The analysis presented here does not have a temporal component, but rather identifies the functions that are most likely to require attention to facilitate ISP.

Both the structural and the functional theories identified cases of innovation system failure. The functional theory identified more paths for failure to innovate than the structural theory. Additionally, more conditions in the functional theory contribute to innovation failure than in the structural theory. The causes of failure to innovate were not random; they followed patterns (configurations of weak conditions) and could be identified through analysis of those conditions. The conditions of the structural theory were more consistent over many cases, whereas the conditions of the functional theory were more variable from case to case. The structures are more constant than the functions within this IS.

8.4. Application of innovation systems at the project level

In the studies described here, the concepts of sectoral and technological IS have been applied at the R&D project level, where the minutiae of innovation occur. We have argued that, at this project level, the structural and functional IS failure frameworks can be constituted and tested as theories. For the IS at the intersection of food safety (technology) and the Australian red meat industry (sector) all elements of the IS need to be strong to result in strong ISP and therefore, certainty of producing innovation outcomes from projects. Those responsible for projects situated within both sectoral and technological IS should consider the insights afforded by both system failure theories in the design and management of projects to identify and correct weaknesses that might exist.

IS approaches, through the structural and functional frameworks, offer analysis of system weaknesses and the possibility of intervention in a system that behaves in consistent ways. Markard, Hekkert and Jacobsson (2015, p. 79) suggest that, in addition to being used as an analytical construct, an IS "exists 'out there' and can be identified and described empirically". This work exemplifies both positions. Use of QCA determined conditions that were weak in those projects that had poor ISP, and strong in those with more certain ISP. The system, as defined by the boundaries used in this research, demonstrated a consistency in the causes of poor ISP at the project level. The consistency, observed through the application of both structural and functional weakness theories is evidence that the innovation system has a reality that can be understood, predicted and possibly prevented or rectified through policy or management intervention to modify the behaviour of the system.

The objective of IS analysts has always been to intervene, usually through policy, in order to improve ISP. At the project level, both policy and managerial interventions can ameliorate weak system conditions. Many structural weaknesses identified in the framework are more effectively rectified through policy, where functional weaknesses can often be rectified by management at the project level. For instance, structural elements of infrastructure and institutions are amenable to policy change, while interactions among appropriate and competent actors may be managed at the project level. In the functional framework, weakness in legitimation of the technology may require a policy intervention, but weak guidance of the search, knowledge development or knowledge dissemination may be rectified by management at the project level. Intermediaries may take responsibility for the management of the system at the project level (Dhanaraj & Parkhe 2006; Howells 2006).

We have demonstrated that, at the project level, weaknesses can be identified across sectoral and technological frameworks. This raises questions about how these system elements may be related. An improved understanding of the relatedness of IS weaknesses may lead towards a better understanding of the root causes, and therefore correction, of weaknesses. We argue that there are advantages in analysing the system through both analytical lenses to more adequately identify all the causes of IS weakness and improve ISP. The studies presented here make a strong case for formally combining the analytical structural and functional frameworks when analysing innovation projects that can be placed at the intersection of these systems as suggested by some scholars. Identification of system weaknesses would not only have the potential to positively improve the innovation outcome of the project concerned, but also improve the performance of the whole IS, and lead to the economic benefits sought by investors and governments.

The theories of sectoral and technological IS failure would benefit from further analysis at the project level. Further studies are required to thoroughly test the theories through more diverse case studies and data sets. These should investigate the relationships between weaknesses among system elements, the dynamics among these over time and the degree to which different conditions or parameters contribute to innovation outcomes over different timescales. Evaluative or action research case studies should examine whether and how amelioration of system weaknesses through interventions can affect innovation outcomes, providing opportunities for further theory development.

9

Discussion and conclusion

9.1 Introduction

The purpose of this chapter is to collate and further discuss the results from the studies conducted (chapters 4-8) and their contributions, provide formal answers to the research questions, consider the limitations of the studies and suggest directions for further research.

The research was motivated by the practical desire to better understand how to manage industry innovation arising from research. The research conducted contributes to a theoretical understanding of innovation systems, the importance of intermediaries, and the application of QCA to IS research at the project level and as a tool for theory testing. In addition, the research contributes to policy by exploring the use of innovation systems at a project level and how critically important IS actors such as intermediaries, and researchers, are to IS performance. Likewise, the research provides a project level perspective of IS for practitioners who are attempting to facilitate innovation outcomes in often complex and, until this study, the largely opaque networks of IS actors most of whom have agendas in which innovation is only a small part.

9.2 Innovation systems

The innovation systems approach was chosen as the framework for investigation because of its potential relevance to the management of innovation projects, the promise of improving innovation performance (Edquist, Charles 1997), and the degree of acceptance by national governments (Dodgson et al. 2011; Manjón & Merino 2012) and international bodies (Organisation for Economic Co-operation and Development & Statistical Office of the European Communities 2005).

Innovation systems scholars have largely been content to maintain a conceptual approach and ambiguity (Bergek et al. 2015; Markard, Hekkert & Jacobsson 2015). Innovation systems analysis has generally been conducted at a high level; an industry sector, or with a technological focus perhaps limited by geographical boundaries (Chapter 8). The studies described in this thesis have attempted to be more explicit, reduce ambiguity, and develop an understanding that may be useful to practitioners at the project level.

9.2.1 Innovation systems as theory

At the core of both studied innovation system frameworks (Bergek et al. 2008; Klein Woolthuis, Lankhuizen & Gilsing 2005) a theoretical proposition was stated, that all the elements (either structural or functional) of the innovation system needed to be operating adequately in order for the system to perform, and for innovation to result. These propositions were tested (Chapter 4) using multiple food safety projects conducted in the Australian red meat industry.

When constructed and tested as theory, both the structural and functional weakness theories explained innovation system performance, within the limitations imposed by the collected case studies. In all cases (projects) examined, weakness in one element of a theory leads to innovation failure. It has not been possible to prove the theories, but no evidence collected falsified the theories.

Neither theory appears to be superior to the other in identifying conditions that lead to poor innovation system performance (Chapters 4 and 5). Both the structural weakness theory and the functional weakness theory are capable of predicting innovation system failure with acceptable goodness of fit parameters in QCA. The functional weakness theory identifies more paths for poor innovation system performance than the structural theory. Additionally, more conditions in the functional weakness theory contribute to innovation failure than in the structural weakness theory. These findings suggest that the conditions of the structural theory are more consistent over many cases, whereas the conditions of the functional theory are more variable from case to case. The structures are somewhat constant in comparison to the dynamic functions within an innovation system.

Analysis of indicators, in a formative measurement system, for recurrently weak conditions, demonstrates that many indicators are almost equally significant in forming those conditions (Chapter 6). This finding suggests that, like the requirement for all conditions to be effective for innovation system performance, many indicators, defined by the measurement system, contribute to the effectiveness of those conditions.

The consistency of the data collected through the use of the survey instrument, and analysed through fsQCA, with theory, suggests that both the instrument and an analytical methods may provide a suitable approach to the analysis of innovation systems and diagnosis of system weaknesses.

9.2.2 Innovation systems as policy instruments

Innovation systems are not simply theories or analytical constructs; they are comprised of real actors, shaped by government policy, with critically important innovation outcomes that have consequences for organizational, sectoral, and national economic competitiveness. The system chosen for analysis, food safety innovation in the Australian red meat industry, operates as a system, with the projects failing to lead to innovation often having similar innovation system weaknesses (Chapter 5). These recurring weaknesses suggest that, rather than the projects failing by chance, at least some failure is predictable and prediction of failure may be based on the diagnosis of weak innovation system conditions that are manageable through policy and practice interventions.

Wieczorek and Hekkert (2012) discuss the need to develop systemic instruments, that is, strategies and tools that can be applied to overcome system weaknesses and improve innovation system performance. van Mierlo et al. (2010) discuss how a specific policy instrument was applied to increase learning and innovation performance. The use of innovation system weakness frameworks are yet to be used to guide interventions at the project level.

9.3 Intermediaries

Although interactions are identified as an element in the structural weakness framework (Klein Woolthuis, Lankhuizen & Gilsing 2005) and networks are identified as a structural component in the functional weakness framework (Bergek et al. 2008), little scholarship has investigated the significance of networks and interactions on innovation outcomes.

This study has demonstrated the significant impact on innovation outcome of the involvement of a large number of innovation system actors in a project (Chapter 7). Also demonstrated is the importance of the intermediary in ensuring innovation system performance.

The intermediary was perceived by the other actors to be highly involved and effective in a high proportion of cases and significantly more involved and effective in cases with an innovation outcome. The Intermediary's effectiveness was necessary to the strength of innovation system conditions that had a tendency to be weak.

It is suggested that effectiveness of actors in the innovation system is determined by their contribution to the strength of innovation system conditions, either through their own effort in effectively applying resources to the innovation system or acting as a conduit for the contribution of others, thus ensuring innovation system performance.

9.4 Qualitative Comparative Analysis

QCA, including the approach using fuzzy sets, has been used for over 25 years (Rihoux & Marx 2013b), but has only recently become more prominent in the analysis of data in innovation and business studies (Rihoux et al. 2013). The application to business and innovation research owes much to the Global Innovation and Knowledge Academy (www.gika-academy.com) and to Woodside (2010, 2013, 2014, 2016) and Woodside, Ko and Huan (2012).

QCA is a relatively rapid and simple analytical tool, but needs to be approached carefully, drawing from the wealth of understanding from analytical experts. Rihoux and Ragin (2009) and Schneider and Wagemann (2012) have produced basic texts. Significant issues in the analytical method and theoretical approaches continue to arise and need to be considered. For example, a recent publication (Baumgartner & Thiem 2015) describes a significant problem with the algorithm for truth table reduction in the most popular software program. Dul (2016) and Vis and Dul (2016) suggest an analysis they call Necessary Condition Analysis which is, perhaps, better able to quantify the relevance of necessity conditions, by expressing the level of condition necessary to achieve an outcome. The studies described here contribute to the practice of fsQCA and theoretical development.

9.4.1 Testing theory

Schneider and Wagemann (2012) present an argument for the incompatibility between deductive theory testing and usually inductive application of QCA, which is based on an argument that inferential statistics "are the cornerstone of most mainstream hypothesis-testing statistical approaches" (Schneider & Wagemann 2012, p. 296). They do, however, allow that the evaluation of theory may occur using set theoretic approaches even if not frequently used in the literature.

This study demonstrates the value of QCA methods in developing theoretical statements that allow testing, and conducting analysis to test theory (Chapter 4). When developing theoretical statements, QCA demands the statement of the theory in definite, logical terms that admit both the presence of conditions leading to an outcome and the causal relationship.

9.4.2 Fuzzy set calibration

A key aspect of fuzzy-set QCA is the selection of the points used for calibration: the maximum value for cases totally outside the set, the minimum point for cases totally inside the set and the point of indifference separating cases more in the set than out of the set from those that are more out of the set than in the set. Two approaches to fuzzy-set calibration in QCA are suggested in the literature. One approach (Schneider & Wagemann 2012) promotes the selection of points that are based on theoretical knowledge and empirical evidence about the condition or outcome and the other (Woodside 2010, 2013, 2014) promotes the use of statistically selected values for calibration. Both approaches have been used in this study.

For the purpose of theory testing (Chapter 4) the points were chosen based on a consensus view of the researchers of the values. In this respect, it represented a value judgement; a judgement of the quantum of each condition necessary to contribute to innovation system performance. It was found that only minor adjustment of these values was required to produce excellent goodness of fit parameters for the deduced models.

For the purpose of detecting recurrently weak conditions (Chapter 5) recalibration of conditions was conducted, following the recalibration of the outcome, to ensure conformity of conditions and outcome with the innovation system theory. This approach to calibration forced diversity into the calibrated data that was not otherwise apparent. Recalibration of the outcome (measured on a Likert scale) meant that a higher certainty of achieving an innovation outcome was required for set membership. For the condition, this method indicates the magnitude of point of indifference of the condition (measured on a Likert scale) necessary to produce a high level of innovation certainty. Determining the quantum of any condition required to produce a high level of certainty of an innovation outcome is of practical significance.

The derivation of situationally-derived calibrations for conditions and outcomes can be valuable when the parameters are defined within the study, are continuously variable, and amenable to interventions to induce change.

9.4.3 Causal recipes

QCA claims the ability to identification causal configurations or recipes leading to an outcome (Berg-Schlosser et al. 2009; Ordanini, Parasuraman & Rubera 2014).

The study to test theory (Chapter 4) is an example of producing solution formulas for the relationship between conditions and outcome and directly comparing it with theory. The analysis was then extended (Chapter 5) to seeking sets of conditions to explain a higher level of certainty of achieving the outcome, and could be done with some confidence because the theoretical basis was assured. The study to determine the root cause of innovation system problems amongst the indicators (Chapter 6) provides an example of the potential problems of taking a number of conditions and assuming that the model is the only explanatory possibility simply because the goodness of fit parameters are acceptable. When examining the use of indicators for constructing the conditions leading to innovation system performance, several alternative configurations of indicators could be constructed, each almost as acceptable, assessed by goodness of fit parameters, as the other.

Berg-Schlosser et al. (2009) discuss the significance of theory at all stages of QCA: selection of conditions to be included in the model, during analysis in making decisions about truth table minimisation and during interpretation to make decisions about equally acceptable solutions and justify choosing between them. Schneider and Wagemann (2010) suggest a standard of practice for QCA that a solution alone should not be taken as demonstrating a causal relationship between conditions and outcome.

9.4.4 Measurement systems and constructs

The QCA method usually involves a direct relationship between the condition and the outcome. QCA has generally not utilised multiple layers of causal complexity, or layers of measurement and causation, such as found in approaches such as structural equation modelling.

In the studies described here, a formative measurement model for conditions was used, the validation of which is problematic (Diamantopoulos, Riefler & Roth 2008; Diamantopoulos & Winklhofer 2001). However, this model of measurement, in which indicators are considered to form the measurement (condition), is epistemologically consistent with the QCA assumption that conditions may be causal antecedents of the outcome.

This work on measurement model validation (Chapter 6) explores an approach using a two-layered approach to QCA: a measurement layer in which indicators are used to form the condition, and the familiar relationship between conditions and outcome. The validation of the measurement model was explored using qualitatively the criteria used in confirmatory factor analysis (Hair et al. 2014), and QCA methods (Chapter 6). This analysis is somewhat preliminary.

Huarng (2016) proposes an approach to multi-level models using QCA, through the calculation of a measure called "new consistency" which is suggested as being more appropriate for use in multi-layer models. Huarng's approach appears to be more complete than the proposal made in this study.

9.5 Answers to research questions

The previous sections, outline the findings of the studies conducted, and provide evidence to address the study’s research questions. The findings, discussed in this and earlier chapters, are summarised in this section in order to answer the research questions.

RQ1: Does the structural framework of innovation systems explain the ability of research to lead to innovation?

In order to answer research question one, the theoretical claim of the structural framework was subjected to testing using data collected for a range of projects and fsQCA (Chapter 4). The theory was also tested using the same data with increasing certainty being applied in the calibration of the innovation outcome (chapter 5).

The structural theory conditions were all necessary and sufficient for an innovation outcome using initially selected set membership calibration, which identified a low diversity of cases. All cases conformed to theory and goodness of fit parameters were acceptable (Chapter 4). Lack of certainty of an innovation outcome in a more diverse data set, developed through fuzzy set recalibration, resulted from sets of conditions, revealed through fsQCA, in which at least one condition was weak. The significance of weakness in structural theory conditions to lower certainty of an innovation outcome was supported by a statistically significant increase in the risk of lack of innovation outcome in cases with a weak structural condition (Chapter 5).

As far as able to be tested with the available data, the theory within the structural framework of innovation system failure was able to explain the ability of research projects to lead to an innovation outcome.

RQ2: Does the functional framework of innovation systems explain the ability of research to lead to innovation?

In order to answer research question two, the theoretical claim of the functional framework was subjected to testing using data collected for a range of projects and fsQCA (Chapter 4). The theory was also tested using the same data with increasing certainty being applied in the calibration of the innovation outcome (chapter 5).

The functional theory conditions were all necessary and sufficient for an innovation outcome using initially selected set membership calibration. Forty out of 41 cases conformed to theory (Chapter 4). Lack of certainty of an innovation outcome in a more diverse data set, developed through fuzzy set recalibration, resulted from sets of conditions, revealed through fsQCA, in which at least one condition was weak. The significance of weakness in structural theory conditions to lower certainty of an innovation outcome was supported by a statistically significant increase in the risk of lack of innovation outcome in cases with a weak structural condition (Chapter 5).

As far as able to be tested with the available data, the theory within the functional framework of innovation system failure was able to explain the ability of research projects to lead to an innovation outcome.

RQ3: Does a combination of both the structural and functional frameworks better explain the ability of research to lead to innovation?

Each theory is able to explain the elements that need to be present in order to achieve an innovation outcome. The functional theory identifies a larger number of cases, as well as alternate configurations, leading to lack of innovation system performance than the structural theory. While a combination of both theories identifies additional conditions to ensure innovation, such combination does not identify additional cases of low membership of the innovation set (Chapter 4).

When applying increasing certainty of innovation to the calibration of the innovation outcome, many cases at all levels of calibration demonstrated recurring weakness in a few conditions (Chapter 5). More conditions in the functional theory contribute to innovation failure than in the structural theory. Some conditions in each theory are recurrently weak, and the weakness in these conditions is associated with an increased risk of lack of innovation.

The demonstration, at the project level, that weaknesses can be identified from both structural and functional theories in projects with lack of innovation raises the question of how these system elements may be related. There was no obvious correlation between the conditions of one theory and the other, so this question is open to further research. Until a better understanding is reached, there is a pragmatic advantage to analysing the system through both analytical lenses. The studies presented here make a strong case for formally combining the analytical frameworks afforded by the structural and functional theories as suggested by some scholars (Chapter 8).

9.6 Implications

This research has implications for practice and policy in answer to the secondary research question and the practical questions posed (Chapter 1).

9.6.1 Rural R&D system

How significant is the role of the Rural Development Corporation as intermediary in the innovation system?

The study on the role of actors in the innovation system provides evidence for the significant role of the intermediary, the RDC (Chapter 7). The intermediary was significantly more involved and effective in cases with an innovation outcome. The Intermediary's effectiveness was necessary to ensure the strength of most of the innovation system conditions that were recurrently weak in this system.

Despite the involvement of the intermediary in each project, the actions taken by the intermediary were not always successful in ensuring sufficiently strong innovation system performance and an innovation outcome. This research does not provide evidence of innovation system performance in the absence of the intermediary.

Beyond being the conduit for funding, the intermediary has a role to ensure that the innovation system conditions are strong. It is suggested that the role of the intermediary is to ensure that all of the elements identified by the structural and functional theories are sufficiently applied to each project.

9.6.2 Innovation policy

How can public and industry funds be applied most effectively to achieve food safety innovation in the Australian red meat industry?

This research suggests that the effective use of funds occurs when they are applied to develop the whole of the innovation system and when an intermediary is designated to ensure that the system is operating effectively. Arguably, funds are only needed when innovation system elements are weak.

Many of the elements of the structural theory are amenable to policy intervention. The competence of actors, effective hard institutions, and adequate infrastructure may all be addressed by policy. It is likely that other conditions, such as the presence of sufficient actors (Chapter 7), cannot be directly addressed by policy. However, if sufficient actors cannot be induced to be involved in an innovation project, then it may indicate that other conditions, such as markets, are not sufficiently strong to attract actors to the project (Chapter 6).

The elements of the functional theory are most often able to be addressed within the system, that is, by project management. Funds must, however, be applied beyond the usual areas of knowledge development and dissemination. It is tempting for the intermediary and the researchers to think that funding and producing research, embodied in a scientific paper or industry-oriented report is sufficient. This research provides a clear challenge that interaction between all the stakeholders, direction given to the outcome, acceptance of ideas, approaches and solutions, dissemination of knowledge, practical experimentation, and so on, are all required if investment is to be effective in leading to innovation.

Given the importance of the intermediary demonstrated by this study (Chapter 7), policy-makers should ask whether other areas of technological development would benefit from a designated intermediary organisation such as occurs in Australian rural industries.

9.6.3 Innovation project management

How can managers of industry projects ensure that food safety innovation is more likely as a result of research?

Project managers should ensure that all of the elements of both the structural and functional theories are operating sufficiently well such that they do not limit the ability of their project to result in innovation. This research has not investigated how project managers can gauge the strength of conditions pre-emptively or the strength of conditions required. The interaction of competent actors is probably the most important aspect of the structural theory that can be managed within the project; the other elements may be largely outside the project. Many elements of the functional theory may be best addressed at a project level, by the actors involved in the system. Direction of the search, knowledge development and dissemination, acceptance, and entrepreneurial experimentation may all be addressed by the decision of innovation system actors, providing that sufficient actors have been involved.

Project managers also must consider their role as innovation intermediaries.

9.7 Limitations

There are limitations to the studies described here due to the choice of case study and the selected methods.

The chosen case study, at the intersection of a single sectoral and technological system, provided multiple cases with many aspects controlled across cases, allowing the effects of the structural and functional theory elements to be assessed. The limitation that this imposed is the limited ability to generalise from this case study to others. However, the theories tested in this research were already supported with empirical data, both in their conceptual formation and scholarly application since formulation (Chapters 2 and 8). The features of the innovation system that may allow generalisation may include a sector characterised by strong institutional control (regulation), a technology that is knowledge intensive and the presence of a dedicated intermediary organisation.

It transpired that the cases in this innovation system had little diversity. Given that it is possible only to falsify theory, the low diversity of cases, with a limited number of cases with failure to innovate, resulted in the testing of theory being less complete than desirable (Chapter 4). However, lack of diversity was overcome by the use of different fuzzy set calibration and the production of a model with good fit between innovation system conditions and outcomes (Chapter 5).

The TIS framework emphasises the temporal development of the systems as functions (conditions) are required for system development. The temporal arrangement of innovation systems functions were not examined. However, the inclusion of only completed cases in the study ensured that all functions were able to be examined.

It is possible that there was bias in responses to the survey. Every attempt was made to recruit and receive responses from as many informants as possible for each project. However, responses were likely to be biased towards projects judged as successful by participants. There may also have been bias by respondents in favour of the project manager, who was also conducting the survey. Efforts were made to conduct the survey to minimise bias toward the project manager or intermediary organisation. The use of multiple informants for each case, the calibration the data when calculating fuzzy set membership and the QCA approach to analysis reduced the potential impact of bias in responses.

9.8 Directions for further research

Four areas for further research would continue to develop theory and practice in the application of innovation systems at the level of projects. These areas suggested for further research are: examination of other innovation systems, understanding how conditions between the systems are related and affect each other, understanding the dynamic nature of innovation system conditions and how policy and management can strengthen conditions at appropriate times in the life of a project, and determining appropriate interventions in a project using an innovation system weakness framework. In all of these research areas, the role of intermediaries should also be investigated and understood.

The applicability of the sectoral and technological innovation system weakness framework, and the survey instrument, would be much more certain if case studies were performed in other innovation systems, with and without an intermediary organisation. Not only does the innovation failure framework need to be evaluated in many innovation systems at the project level, but the use of the survey instrument also needs to be evaluated and validated. Further work is required to determine the best way of validating a formative measurement system model in QCA.

A better understanding can be gained of how the conditions of the frameworks relate to one another, and how the two frameworks relate to one another Collecting data on other innovation systems and increasing the diversity of the data set may allow provide the opportunity for this to happen. There are likely overlaps and ambiguities in definition of innovation system conditions that need to be clarified, and possibly a hybrid structural-functional weakness framework developed. The data may come through continued use of survey methods as used in this research, but may also require a qualitative longitudinal studies (for example, ethnography) and in depth understanding of the position and decision-making of actors, similar to that used by van de Ven in the Minnesota Innovation Research Program (van de Ven & Angle 2000).

An understanding of the dynamic nature of innovation system conditions, the developing network of system actors and the role of intermediaries may also come from qualitative longitudinal studies. Such studies would provide a basis for understanding of how to strengthen conditions at appropriate times in the life of a project, and determining appropriate interventions in a project using an innovation system weakness framework.

The development and application of interventions in innovation systems to increase the likelihood of success, may occur through the application of an action research methodology. A range of longitudinal projects, with data collection, reflection, and intervention with appropriate system instruments would provide opportunities to understand how to utilise and apply innovation systems weakness frameworks in practice.

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A1

Project Descriptions

The survey instrument provided a description of the project for which data was being collected. In most cases a description contained a link to one or more comprehensive project descriptions and copies of project reports. The descriptions are reproduced here, with references replacing the links to external websites and documents. The case codes match the codes and data in Table 4.1.

A1.1 Case 01 - Antibiotic Resistance

The PROJECT called Antibiotic Resistance was commenced after the JETACAR report had recommended research on antibiotic resistance. The project was directed towards providing data which indicates the prevalence of antimicrobial resistant bacteria in red meat production animals, carcasses and retail meat, and the impact of antimicrobial use on antimicrobial resistance selection. It was anticipated that the results would benefit the Australian red meat production industries in managing the requirements of animal production, public health issues and global trade.

The research phase was conducted by CSIRO, particularly Robert Barlow and Kari Gobius between May 2001 and June 2007. You can find more information about the work here [link to a description and final report for A.MFS.0061].

The research resulted in a number of scientific publications and conference presentations to scientific audiences. New methods were developed and similar antibiotic resistance was found in cattle from different production systems. The research was used by CSIRO as a basis for an Australian Government funded project surveying antibiotic resistant bacteria in Australian food.

A1.2 Case 02 - Risk management - Listeria in smallgoods

The PROJECT called Risk Management - Listeria in smallgoods was commenced to assess the risk of listeriosis from Australian smallgoods, following large outbreaks in the USA, and went on to evaluate the use of compounds such as lactate and diacetate to prevent the growth of Listeria in processed meats.

The research phase was conducted by University of Tasmania, particularly Tom Ross and Lyndal Mellefont between January 2000 and February 2011. You can find more information about the work here, here, and here [link to descriptions and final reports for PRMS.012, A.MFS.0071, A.MFS.0244].

The research resulted in a risk assessment that was published in a scientific journal and practical work that was presented in industry workshops and in industry publications on control of Listeria in processed meats. The work showed that only some smallgoods presented a risk of listeriosis and that the use of preservatives could prevent the growth of Listeria making them much safer.

The research was used by MLA to suggest changes in the Food Standards Code and to encourage reformulation of processed meat products.

A1.3 Case 03 - Stasis and inactivation of bacterial pathogens on meat and meat products

The PROJECT called Stasis and inactivation of bacterial pathogens on meat and meat products was commenced because there was a need to understand how to prevent growth and inactivate pathogens such as Listeria monocytogenes, Salmonella and E. coli.

The research phase was conducted by University of Tasmania, particularly Tom McMeekin and Tom Ross between July 2000 and June 2003.

The research resulted in a large number of publications in the scientific literature, and major conference presentations promoting predictive microbiology, with models being developed for determining growth/no growth of Listeria and E. coli, a comprehensive model for the growth of E. coli, an understanding of how Listeria adjusted to growth at different temperatures, and how E. coli and Salmonella responded to abrupt shifts in temperature and water activity (lag phase, and death).

The research was used by the hot boning panel as a basis for the hot boning index, which later became the refrigeration index. You can read about the refrigeration index here [link to MLA Refrigeration Index Calculator page at the Food Safety Centre website].

A1.4 Case 04 - E. coli in fermented meats

The PROJECT called E. coli in fermented meats was commenced because of the need to be able to control E. coli in fermented meat products, such as Salami following outbreaks.

The research phase was conducted by University of Tasmania and CSIRO particularly Tom Ross, Craig Shadbolt and Paul Vanderlinde between October 2000 and December 2002. You can find more about the work here [link to E. coli Inactivation in Fermented Meats page at the Food Safety Centre website].

The research resulted in a number of scientific publications on E. coli inactivation, and communication to industry and regulators at workshops. The work showed that the death of E coli during the manufacture of fermented sausages was best predicted by following the time and temperature of the production process.

The research was used by FSANZ and other regulators for determining the safety of fermented sausage production processes.

A1.5 Case 05 - ESAM data analysis

The PROJECT called ESAM data analysis was commenced to examine the scientific underpinnings of the ESAM program, especially since the industry considered that the 2000 Meat Notice was too stringent

The research phase was conducted by CSIRO and NSW DPI, particularly Paul Vanderlinde and David Jordan between December 2000 and June 2002.

The research resulted in one scientific publication on setting microbiological standards. The direction of the work was determined by a panel, who also signed off on the recommendations.

The research was used AQIS for revising the ESAM Meat Notice 2003/6

A1.6 Case 06 - Salmonella in goat and goat meat

The PROJECT called Salmonella in goat and goat meat was commenced because of the high prevalence of Salmonella on goat carcases in the ESAM program.

The research phase was conducted by CSIRO, particularly Paul Vanderlinde between July 2001 and June 2002.

The research resulted in a scientific publication on the prevalence and serotypes of Salmonella in goats at two abattoirs.

The research was used by FSANZ for providing information for developing the Meat Primary Production and Processing Standard.

A1.6 Case 07 - Safe feeding strategies for beef production in Northern Australia

The PROJECT called Safe feeding strategies for beef production in Northern Australia was commenced because there were suggestions that a molasses based diet could reduce pathogenic E. coli carriage in cattle

The research phase was conducted by CSIRO as part of the beef quality CRC, particularly Chris McSweeney, Denis Krause, Stuart Denman and Rosalind Gilbert between July 2001 and May 2005.

The research resulted in a large number of publications in the scientific literature on methods of analysis, populations of E. coli under different feeds and the potential to use this as a finishing diet prior to slaughter.

The research demonstrated a reduction in E. coli in the faeces, but reduced weight gains compared to conventional diets.

A1.8 Case 08 - Surveillance techniques for food-borne hazards in livestock and livestock products

The PROJECT called Surveillance techniques for food-borne hazards in livestock and livestock products was commenced because improved management of foodborne hazards could result from better understanding of the limitation of surveillance techniques and better design of surveillance studies.

The research phase was conducted by NSW DPI, particularly David Jordan between June 2001 and December 2002.

The research resulted in a couple of publications on pooled faecal sampling and the sensitivity of immunomagnetic separation.

The research was used MLA for the design of studies for O157 prevalence in cattle and the 3rd industry baseline on meat.

A1.9 Case 09 - E. coli O157 and Salmonella in red meat animals and processing

The PROJECT called E. coli O157 and Salmonella in red meat animals and processing was commenced because Salmonella and pathogenic E. coli were known to be shed by cattle, but little was known about the pattern of shedding

The research phase was conducted by CSIRO, particularly Trish Desmarchelier and Narelle Fegan between June 2001 and June 2007. You can find out more about the work here and here [links to descriptions and reports for PRMS.030 and A.MFS.0060].

The research resulted in a number of scientific publications, Meat Technology Updates from CSIRO scientific conferences in Australia and overseas and industry workshops. Methods for E. coli O157 were developed and a survey of shedding in faeces was conducted. The transfer from faeces to carcases was demonstrated at an individual animal level.

The research was used AQIS for responding to FSIS requirements and by FSANZ for informing the development of the Primary Production and Processing Standards

A1.10 Case 10 - High pressure processing of smallgoods

The PROJECT called High pressure processing of smallgoods was commenced because high pressure allows smallgoods to be processed at low temperatures and without the use of preservatives and was already being used in other countries.

The research phase was conducted by CSIRO particularly Cindy Stewart and Melinda Heyman between June 2002 and June 2003. You can find out more about the work here [link to project description and report for PRMS.033].

The research resulted in a scientific paper and at industry workshops. High pressure was shown to be effective in treating three products with.

The research was used MLA to promote high pressure as an effective treatment to reduce Listeria risks.

A1.11 Case 11 - Investigation of alternative to 82°C water for knife and equipment sterilisation

The PROJECT called alternatives to 82°C water for knife and equipment sterilisation was commenced because although the need for a minimum water temperature of 82°C had been questioned previously, the necessary alternative protocols had not been prepared to the satisfaction of AQIS, other Australian regulatory authorities and regulatory authorities of importing countries.

The research phase was conducted by CSIRO, particularly Ian Eustace, Jocelyn Midgley and Alison Small between February 2002 and November 2006. You can find out more about the work here and here [links to project descriptions and final reports for PRMS.076 and A.MFS.0115].

The research resulted in the publication of an industry guide, some scientific publications, and presentations to a number of industry meetings. These publications showed exactly how lower temperature sterilisation of knives and equipment could be introduced, depending on the time available for knives to be in the water.

The research was used by MLA to gain approval from Meat Standards Committee for an alternative knife treatment process.

A1.12 Case 12 - Red meat industry through-chain risk profile

The PROJECT called red meat industry through chain risk profile was commenced because regulators wanted a consolidated understanding of risks associated with red meat, and industry was agreeable to something that would put future quality assurance into a risk context.

The research phase was conducted South Australian Research and Development Institute, particularly Andy Pointon between February 2002 and June 2003.

The research resulted in a number of scientific publications, a report (on CD) which was kept confidential to SAFEMEAT, and a symposium for all stakeholders to describe the results. The research was used by FSANZ as a basis for their risk assessment for the meat Primary Production and Processing Standard, and by MLA to justify the technical elements of Livestock Production Assurance.

A1.13 Case 13 - Tag scores at Australian cattle abattoirs

The PROJECT called tag score at Australian cattle abattoirs was commenced because of a desire to compare US and Australian processing systems when control of E. coli O157 became an issue.

The research phase was conducted by NSW DPI particularly David Jordan between February 2003 and March 2003.

The research resulted in a final industry report, concluding that tag, ie mud and faeces, on cattle was a lot less in Australia than in the USA

The research was used AQIS for responding to FSIS in March 2003 and by MLA in presentations justifying the Australian industry position on E. coli O157 to US industry audiences.

A1.14 Case 14 - Carcase chilling as an intervention

The PROJECT called Carcase chilling as an intervention was commenced because FSIS encouraged, and US customers were asking, for validated interventions against E coli.

The research phase was conducted by CSIRO, University of NSW, and University of Tasmania, particularly Neil McPhail, Tuan Pham and Tom Ross between June 2003 and August 2005. You can find out more about the work here [link to project description and report for A.MFS.0043].

The research resulted in final project reports and scientific publications on the drying of carcases during chilling. The researchers produced combinations of carcase chilling models and predictive models

A1.15 Case 15 - Potential pathogens

The PROJECT called Potential Pathogens was commenced because a risk profile had indicated that several potential pathogens might be associated with meat, and there was an agreement that industry should be prepared should these pathogens become an issue.

The research phase was conducted by CSIRO, particularly Paul Vanderlinde and Lesley Duffy between November 2003 and June 2006.

The research resulted in presentations at conferences and one scientific publication on Arcobacter. The pathogens E. coli O111 and O26, Arcobacter and Aeromonas were shown to be infrequently found in red meat samples.

The research was used MLA as assurance that no further work was warranted in these areas for public health reasons.

A1.16 Case 16 - Microbiological survey of Australian red meat

The PROJECT called Microbiological survey of Australian red meat was conducted to collect baseline data on pathogens and indicator bacteria in Australian beef and lamb.

The research phase was conducted by Symbio Alliance, particularly David Phillips between December 2003 and August 2004 and again between October 2010 and December 2011. You can find out more about the work here [link to project description and report for PRMS.045].

The research resulted in industry publications and meetings as well as publications in the scientific literature, and showing the high standard of processing of Australian carcasses, boneless meat and primals.

The research was used MLA for many presentations to overseas markets as well as supporting data for the safety of Australian red meat products.

A1.17 Case 17 - Variables in processing - effect on micro quality

The PROJECT called Variables in processing - effect on microbiological quality was commenced because there was a desire to determine the factors that could result in better or poorer microbiological quality of carcases

The research phase was conducted by CSIRO, SARDI and Symbio Alliance particularly P. Vanderlinde, A, Kiermeier and D. Phillips between September 2003 and July 2006. You can find out more about the work here [link to project description, scientific report and process assessment tool].

The research resulted in industry publications and presentations at conferences and meetings, as well as scientific publications. A number of factors were found, for beef and sheep to relate with higher or lower contamination on carcases.

The research was used by MLA to produce the beef incoming livestock and process assessment tool and the sheep incoming livestock and process assessment tools, that are available on CDs

A1.18 Case 18 - Effect of freezing on the survival of Escherichia coli O157

The PROJECT called Effect of Freezing on the Survival of Escherichia coli O157:H7 was commenced because of pressure on the industry to demonstrate an intervention for E. coli O157

The research phase was conducted by CSIRO, particularly Gary Dykes between December 2003 and May 2007. You can find out more about the work here [link to A.MFS.0097 description and report].

The research resulted in a scientific publication and an industry publication. While the results showed up to 1 log decrease in E. coli O157 during freezing, this kill could not be increased.

The research was used MLA to demonstrate some effect of freezing to US customers and other countries.

A1.19 Case 19 - Cooling of cooked meat

The PROJECT called Cooling of cooked meat was commenced because Meat Standards Committee has a concern that cooked meats were not being cooled according to the requirements of the Australian Standard.

The research phase was conducted by Australian Food Microbiology and a specially convened panel, between October 2003 and September 2004.

The research resulted in an industry publication and conference presentation which showed a low risk and suggested an alternative cooling regime that should be more easily achieved and safe.

The research was used MLA for consideration of the Meat Standards Committee and modification to the Australian Standard.

A1.20 Case 20 - Staph aureus in meat

The PROJECT called Staphylococcus aureus in meat was commenced because high levels of this organism were found in meat at retail and processing practices were thought to be responsible.

The research phase was conducted by Symbio Alliance, particularly David Phillips between March 2006 and November 2006. You can read more about the work here [link to project description].

The research resulted in industry publications and a publication in a food safety journal. The results suggested that the wearing of gloves by processing staff had greatly reduced the incidence of contamination.

The research was used by MLA to suggest that the issue had been dealt with.

A1.21 Case 21 - ESAM analysis and national database

The PROJECT called ESAM Analysis and National Database was commenced because there was a belief that more value could be gained from the ESAM database and a panel was formed to examine the idea.

The research phase was conducted by SARDI, particularly Andreas Kiermeier between March 2006 and January 2010. You can read more about the work here [link to project description and report for A.MFS.0169].

The research resulted in final project reports and industry training in understanding microbiological data. A monthly ESAM report format for distribution to abattoir QA staff was developed.

The research was used by MLA to contract SARDI to produce ongoing monthly microbiological reports. The reports have been used by some plants to demonstrate quality control and process improvements to customers and to objectively benchmark ongoing processing performance.

A1.22 Case 22 - Retail meat microbiology

The PROJECT called Retail meat microbiology was commenced because the microbiological quality of meat at retail was not as high as had been expected in a large baseline study.

The research phase was conducted by Symbio Alliance and CSIRO, particularly David Phillips and Robert Barlow, between August 2006 and February 2008. You can read more about the work here and here [links to project descriptions and reports for A.MFS.0101 and A.MFS.0130].

The research resulted in some industry reports and a conference presentation. The results showed that practices in retail butchery were not as high as expected by regulation.

The research was used by MLA to convene a panel to produce a guide for retail butchers and it was used by FSANZ in their work on Primary Production and Processing Standards.

A1.23 Case 23 - Consolidated customer audits

The PROJECT called Consolidated customer audits was commenced because there was a desire by processors to see customer requirements consolidated with the potential for fewer audits .

The research phase was conducted by Victorian Department of Primary Industry /Symbio Alliance particularly Michelle Edge between September 2006 and February 2008. You can more about the work here [link to description and report for A.MFS.0102].

The research resulted in a final report setting out how a scheme could be conducted and the details of the audit checklists.

A1.24 Case 24 - Curfew in livestock transport

The PROJECT called Curfew in livestock transport was commenced as part of a larger project investigating all impacts from setting feeding curfews for livestock (cattle, sheep and goats) prior to transport.

The research phase was conducted by SARDI and CSIRO particularly Andy Pointon, Andreas Kiermeier and Narelle Fegan between April 2007 and August 2007 consisting of a literature review and transport studies. You can read about the work here and here [links to descriptions and reports for A.MFS.0119 andLIVE.122a].

The research resulted in an MLA report and a scientific publication.

The research was used to justify practices in curfew prior to transport.

A1.25 Case 25 - Mycobacterium paratuberculosis in red meat

The PROJECT called Mycobacterium paratuberculosis in red meat was commenced because a risk profile had identified this microorganism as a potential hazard about which there was a lot of uncertainty.

The research phase was conducted by NSW DPI and University of Sydney, particularly Richard Whittington and Leslie Reddacliff between January 2004 and February 2009. You can read about the work here and here [links to descriptions and reports for PRS.044A and A.MFS.0121].

The research resulted in final reports and several scientific publications, showing that the organism could be found in red meat but was effectively inactivated by usual cooking practices.

The research was used by MLA to assure concerned authorities that this potential risk was adequately controlled.

A1.26 Case 26 - Clostridium difficile in meat

The PROJECT called Clostridium difficile in meat was commenced because of concerns raised in the scientific literature about the presence of this human pathogen in production animals and meat.

The research phase was conducted by University of Western Australia /PathWest, particularly Tom Riley between July 2007 and August 2012. You can read about some of the work here link to project description and reports for A.MFS.0124 and A.MFS.0157].

The research resulted in final project reports, a number of scientific publications and conference presentations that found the organism only in young animals and at low concentrations on meat.

The research was used by MLA as a submission to a Health Department working group.

A1.27 Case 27 - Toxoplasma gondii

The PROJECT called Toxoplasma gondii was commenced because a risk profile had indicated that there was potentially a large risk and large unknowns associated with this pathogen.

The research phase was conducted by SARDI particularly Andy Pointon and Andreas Kiermeier and David Hamilton between September 2007 and March 2008. You can read about the work here [link to project description and report for A.MFS.0129].

The research resulted in an MLA final report.

The research was used as preliminary work to a survey on whether animals have infectious tissues with cysts that are pathogenic for humans.

A1.28 Case 28 - E. coli testing implementation

The PROJECT called E. coli O157 testing implementation was commenced because of moves in the United States towards more stringent requirements for E. coli O157 in beef trim and other components of ground beef.

The research phase was conducted by Symbio Alliance, IEH and CSIRO particularly D. Phillips, M. Samadpour and I. Eustace between August 2007 and January 2008.

The research resulted in presentations to industry and publication in an industry (AMIC/MLA) newsletter for processors. The work provided a feel for the incidence of E. coli O157 in different boning operations across whole days of production and the performance of the AMIC sampling and testing protocol (prior to FSIS rules changing)

The research was used by MLA to inform the industry about this issue and by AQIS to respond to new US regulations about O157.

A1.29 Case 29 - Surface sponging method

The PROJECT called Surface sponging method was commenced because of unexplained differences between ESAM data and baseline data for carcase microbiology.

The research phase was conducted by University of Tasmania, particularly Mark Tamplin and John Sumner between December 2007 and April 2008. You can read more about the work here [link to description and report for A.MFS.0140].

The research resulted in Scientific publications and conference presentations showing how incubation temperature, age of the carcase and sponging method could all affect the result from carcase microbiology.

The research was used to demonstrate the low sensitivity of sponge sampling.

A1.30 Case 30 - Carcase contamination process control

The PROJECT called Carcase contamination process control was commenced to understand how contamination could increase and decrease along a beef slaughter floor.

The research phase was conducted by CSIRO, particularly Alison Small, between April 2008 and May 2009. You can read more about the work here [link to description and report for AMFS.0149].

The research resulted in a conference presentation, industry presentations and a CSIRO newsletter to industry, suggesting that, in situations where hides are relatively clean, other operations may contribute significantly to carcase contamination.

The research was used to demonstrate the variation that can occur.

A1.31 Case 31 - Lymph node microbiology

The PROJECT called Lymph node microbiology was commenced because incising head and thoracic lymph nodes might contribute to contamination of carcases and because indications for mandating routine incision of lymph nodes was becoming increasingly invalid with the eradication of bovine tuberculosis from Australia.

The research phase was conducted by the University of Queensland, particularly Rowland Cobbold between June and December 2008. You can read more about the work here [link to description and report for A.MFS.0152].

The research resulted in a project report showing that these lymph nodes could contain significant numbers of microorganisms including pathogens.

The research was used by the Department of Agriculture for negotiating procedures with the US, for no longer incising lymph nodes.

A1.32 Case 32 - E. coli O157 positive lots

The PROJECT called E. coli O157 positive lots was commenced because a need to better understand and explain contamination that occurred in lots of manufacturing beef

The research phase was conducted by CSIRO and SARDI particularly Robert Barlow, Glen Mellor and Andreas Kiermeier between August 2008 and June 2009. You can read more about the work here [link to description and report for A.MFS.0158].

The research resulted in a scientific publication and presentations at industry meetings, showing that in contaminated lots the contamination was at a low level and not widespread.

The research was used by MLA for communicating to customer groups and being used for a risk assessment on Australian beef.

A1.33 Case 33 - Vacuum packed lamb shelf life

The PROJECT called Vacuum packed lamb shelf-life was commenced because there were no recent data collected under controlled conditions to attest to the shelf-life of chilled, vacuum packed lamb..

The research phase was conducted by SARDI, particularly Andreas Kiermeier between January 2009 and June 2011 with some later involvement of University of Tasmania, particularly Mark Tamplin. You can read about the work here, here and here [links to descriptions and reports for A.MFS.0185, A.MFS.0196 and A.MFS.0238].

The research resulted in a Meat Technology Update published by CSIRO, conference presentations and a scientific publication on lamb shelf-life and microbial communities. The studies demonstrated the long shelf-life of lamb, consumer acceptance despite high counts and the domination of lactic acid bacteria in the product.

The research was used by MLA to support product promotion and by AQIS in arguing for changes in regulations in importing countries.

A1.34 Case 34 - Vacuum packed beef shelf life

The PROJECT called Vacuum packed beef shelf-life was commenced because there were no recent data collected under controlled conditions to attest to the shelf-life of chilled, vacuum packed beef.

The research phase was conducted by CSIRO, particularly Alison Small between December 2007 and September 2008. You can read more about the work here and here [descriptions and reports for A.MFS.0132, A.MFS.0166 and A.MFS.0194].

The research resulted in publication of a Meat Technology Update by CSIRO, presentations at industry and scientific conferences in Australia and overseas, and a scientific publication. The results showed long shelf-life, and unusual microbiological growth profiles dominated by lactic acid bacteria.

The research was used MLA to promote product and AQIS to argue against shelf-life requirements of other countries.

A1.35 Case 35 - E. coli O157 low volume enrichment validation

The PROJECT called Validation of low volume enrichment for E. coli O157 was commenced because sample sizes for testing E. coli for O157 required 375g samples and large volumes of enrichment broth.

The research phase was conducted by DH Micro and Silliker particularly Denise Hughes and Tass Karalis between January 2008 and June 2008. You can read more about the work here [descriptions and reports for A.MFS.0144 and A.MFS.0148].

The research resulted in a scientific publication validating the use of a 1:3 product:broth ratio instead of 1:10 for several rapid test methods.

The research was used MLA to apply to NATA for acceptance of these methods and by AQIS to gain acceptance from FSIS.

A1.36 Case 36 - Understanding shelf life of vacuum packed meat

The PROJECT called Understanding the shelf-life of vacuum packed meat was commenced because there were no modern data on the microbial population in vacuum packed product, or predictive models for how those bacteria grew in vacuum packed meat.

The research phase was conducted by University of Tasmania particularly Mark Tamplin between April 2008 and May 2012. You can read more about the work here, here and here [descriptions and project reports for A.MFS.0147, A.MFS.0194, and A.MFS.0237].

The research resulted in a number of industry presentations, scientific publications and presentations at international conferences. The work has shown how the bacterial communities change over time, has found the dominant bacterial species in Australian meat, how they may differ from one establishment to another, and how to predict the growth rate of these bacteria in vacuum packed beef and lamb.

The research was used MLA to assist processors and exporters with export problems and to explain the shelf-life to customer audiences.

A1.37 Case 37 - Animal disease risk assessment and food safety

The PROJECT called Animal disease and food safety risk assessment and was commenced because there was no agreed approach to assessing the potential for a new animal disease to be a foodborne hazard.

The research phase was conducted by University of Sydney, particularly Michael Ward and Elizabeth Parker between March 2008 January 2009. You can read more about the work here [project description for A.MFS.0150 and link to a scientific article].

The research resulted in a final report, scientific conference presentation and a scientific publication, showing how a new disease could be assessed, using existing diseases as case studies.

The research was used MLA to raise the issue of being able to make these assessments with SAFEMEAT and Animal Health Australia.

A1.38 Case 38 - Epidemiology of human EHEC infection in Australia

The PROJECT called Human Epidemiology of EHEC infections in Australia was commenced because there was no single source of information about the occurrence of disease due to Shiga toxin-producing E. coli in Australia.

The research phase was conducted by Australian National University/LaTrobe particularly Hassan Vally and Gillian Hall between November 2009 and December 2010. You can find out more about the work here [project description for A.MFS.0197 and link to scientific article].

The research resulted in industry presentations, scientific publication and a presentation at a scientific conference showing that Australia has a low incidence of EHEC infections, caused by a variety of E. coli strains, and no documented outbreaks due to beef.

The research was used MLA to support Australia's strong position as a safe provider of beef.

A1.39 Case 39 - Environmental control of L. monocytogenes

The PROJECT called Environmental control of L. monocytogenes was commenced because control of Listeria in smallgoods production environments is difficult, and an idea was presented that seemed to have merit.

The research phase was conducted by EML in Brisbane, particularly Sofroni Eglezos between June and November 2010. You can read more about the work here [project description and report for A.MFS.0219].

The research resulted in industry presentations, scientific conference presentations and a scientific publication, showing that heating and drying production areas could eliminate Listeria.

The research was used MLA for informing the industry of the option

A1.40 Case 40 - Low temperature cooking of meats

The PROJECT called Low temperature cooking of meats was commenced because available tables of times and temperatures for acceptable cooking of meats did not extend over the whole range of temperatures that might be used.

The research phase was conducted by DWC, particularly Darian Warne February 2011 and May 2011. You can more about the work here [project description and report for A.MFS.0248].

The research resulted in a final report

The research was used by MLA in the update to the smallgoods guidelines.

A1.41 Case 41 - nonO157 STEC in Australian cattle and beef

The PROJECT called nonO157 STEC in Australian cattle and beef was commenced of the potential introduction of rules concerning these organisms in the USA.

The research phase was conducted by CSIRO, particularly Robert Barlow and Glen Mellor between July 2007 and June 2010, then a number of laboratories, including Symbio Alliance between November 2011 and February 2012. You can read more about the work [project description and report for A.MFS.0128 and A.MFS.0267-0270].

The research resulted in industry presentations, scientific presentations and publications, showing the low prevalence of the big 6 STEC in Australian cattle and beef products, and how to test for them using rapid methods.

The research was used by MLA to promote Australia's good position to customers and by AQIS to negotiate requirements with the US when rules were introduced there.

A2

Survey instrument

A2.1 Introduction

This appendix reproduces the standard text of the on-line survey. A separate on-line survey was prepared for each project.

The conventions used for presentation are as follows. The sections in this appendix are for the convenience of presentation and an aid to understanding; they were not part of the survey form. Nor did the question numbers, which appear in this appendix within square brackets, appear in the survey form. The question numbers were used in data collation and manipulation, and were used in the 'actors' part of the survey to present appropriate questions to the respondent, based on logical criteria within the survey software. The text also indicates which questions were mandatory and the words applied to Likert scales which were used for many of the questions.

A2.2 Survey Instrument

A2.2.1 Introduction

INNOVATION QUESTIONNAIRE

PROJECT [TITLE OF PROJECT] [on every screen of the on-line survey]

Thank you for participating in this survey. This research study has been explained to you in an information sheet emailed to you on 8 January 2015. Please let us know (ijenson@utas.edu.au) if you would like to have it sent again. Your consent to participate is implied by completion and submission of the questionnaire. If you have questions about this study contact:

Richard Doyle (03) 6226 2622

Ian Jenson 0408 602 903

This study has been approved by the Tasmanian Social Sciences Human Research Ethics Committee. If you have concerns or complaints about the conduct of this study, please contact the Executive Officer of the HREC (Tasmania) Network on (03) 6226 7479 or email human.ethics@utas.edu.au. The Executive Officer is the person nominated to receive complaints from research participants. Please quote ethics reference number H14496.

INTRODUCTION

This is a questionnaire about a single PROJECT conducted by Meat & Livestock Australia (MLA)

DESCRIPTION OF THE PROJECT

[see Appendix 1 for descriptions of the project]

DEFINITION OF THE PROJECT

The PROJECT may include

Consultations about needs and desires, or the identification of opportunities or problems that need to be solved, or in response to regulatory requirements in Australia or overseas
Some kind of research conducted by a consultant, university or other research. Knowledge is produced, and the knowledge in contained in a report for the industry and sometimes reports are published in scientific journals.
Discussions about ways of using the research to benefit the industry, which often requires involvement of several groups, if changes to practices, acceptance of new ideas, changes to regulations etc. are required.

The PROJECT may actually continue for a long time after the research has been completed.

INSTRUCTIONS

This questionnaire is about a single PROJECT, identified above, and asks you to think about all the things that happened between asking whether research should be conducted and all the ways that the research has been used up to now.

This isn't a test of your knowledge; it isn't expected that you will be able to answer all the questions - there is often a 'I'm not in a position to know' choice so that you can indicate that you may not be aware of this aspect of the PROJECT.

Some questions are mandatory (indicated by *). While we encourage you to answer all the questions, you are free to skip questions. All the answers that you give (including 'I am not in a position to know') will be valuable to the research.

You can return to a previous page to change your answer. You can come back to the survey to change your answers. Your responses are submitted when you select the 'done' button on the last page.

A2.2.2 Your role in the project

Your role in the PROJECT

[multiple choice, MANDATORY]

[1]

For the majority of the time with respect to the PROJECT, **to which group did you belong**:

- Researcher
- Red meat industry company
- Industry association or employee representative
- Research and Development Corporation / industry service organisation as employee/consultant
- Government regulator/policy role
- Supplier of goods or services to the industry
- Customer/ consumer of red meat products
- Entrepreneur, funder of research/development
- Other (specify)

A2.2.3 Innovation

Did the PROJECT contribute to something new for the Australian red meat industry?

[7 point scale, MANDATORY]

1 – Strongly disagree

2 – Disagree

3 – Somewhat disagree

4 – Neither agree or disagree

5 – Somewhat agree

6 – Agree

7 – Strongly agree

[2]

Did the PROJECT contribute to NEW PRODUCTS for the Australian red meat industry?

New products

Changed formulation for a product

Changed specification for a product

new claim/s being made for a product already being sold

[3]

Did the PROJECT contribute to NEW PROCESSES being used in the Australian red meat industry?

Implementation of a technology or equipment that was new to the users

Change to techniques or the way that work is performed

Changes to the parameters used to control the process

[4]

Did the PROJECT contribute to NEW SOURCES OF SUPPLY for the Australian red meat industry?

Changing to another supplier of raw materials (including animals or meat) to give a safer product

Changes to the specifications for raw materials (including animals or meat)

[5]

Did the PROJECT contribute to accessing NEW MARKETS by the Australian red meat industry?

Ability to supply new customers/ or new countries

Ability to satisfy changes in customer/market requirements

Decision to withdraw from a market

[6]

Did the PROJECT contribute to NEW BUSINESS MODELS being used by the Australian red meat industry?

Changes in the way that a business interacted with regulators

Changes in the way that a business justified itself to regulators

Changes in regulations

Changes in the way that regulations are enforced

Did/Does the PROJECT have the potential to lead to something new for the Australian red meat industry?

[7]

Did/does the PROJECT have the potential to contribute to (further) NEW PRODUCTS for the red meat industry

New products

Changed formulation for a product

Changed specification for a product

new claim/s being made for a product already being sold

[8]

Did/does the PROJECT have the potential to contribute to (further) NEW PROCESSES being used in the Australian red meat industry?

Implementation of a technology or equipment that was new to the users

Change to techniques or the way that work is performed

Changes to the parameters used to control the process

[9]

Did/does the PROJECT have the potential to contribute to (further) NEW SOURCES OF SUPPLY by the Australian red meat industry?

Changing to another supplier of raw materials (including animals or meat) to give a safer product

Changes to the specifications for raw materials (including animals or meat)

[10]

Did/does the PROJECT have the potential to contribute to (further) accessing NEW MARKETS by the Australian red meat industry?

Ability to supply new customers/ or new countries

Ability to satisfy changes in customer/market requirements

Decision to withdraw from a market

[11]

Did/does the PROJECT have the potential to contribute to (further) NEW BUSINESS MODELS being used by the Australian red meat industry?

Changes in the way that a business interacted with regulator

Changes in the way that a business justified itself to regulators

Changes in regulations

Changes in the way that regulations are enforced

A2.2.4 Actors

[MANDATORY]

Groups involved in the PROJECT

[12]

Were **RESEARCHERS / TECHNOLOGISTS** involved in the PROJECT?

yes [13]

no [14]

I am not in a position to know [15]

[13]

When **RESEARCHERS / TECHNOLOGISTS** were involved

they contributed positively towards the objectives of the PROJECT [15]

they neither contributed positively nor negatively to the objectives of the PROJECT [15]

they made a negative contribution to the PROJECT [15]

[14]

The absence of **RESEARCHERS / TECHNOLOGISTS** from the PROJECT

had a positive impact because their involvement may have caused problems [15]

had no impact because they were not needed [15]

had a negative impact because their contribution was needed [15]

[15]

Were **RED MEAT INDUSTRY FIRMS** involved in the PROJECT?

yes [16]

no [17]

I am not in a position to know [18]

[16]

When **RED MEAT INDUSTRY FIRMS** were involved

they contributed positively towards the objectives of the PROJECT [18]

they neither contributed positively nor negatively to the objectives of the PROJECT [18]

they made a negative contribution to the PROJECT [18]

[17]

The absence of **RED MEAT INDUSTRY FIRMS** from the PROJECT

had a positive impact because their involvement may have caused problems [18]

had no impact because they were not needed [18]

had a negative impact because their contribution was needed [18]

[18]

Were **INDUSTRY ASSOCIATIONS OR EMPLOYEE REPRESENTATIVES** involved in the PROJECT?

yes [19]

no [20]

I am not in a position to know [21]

[19]

When **INDUSTRY ASSOCIATIONS OR EMPLOYEE REPRESENTATIVES** were involved

they contributed positively towards the objectives of the PROJECT [21]

they neither contributed positively nor negatively to the objectives of the PROJECT [21]

they made a negative contribution to the PROJECT [21]

[20]

The absence of **INDUSTRY ASSOCIATIONS OR EMPLOYEE REPRESENTATIVES** from the PROJECT

had a positive impact because their involvement may have caused problems [21]

had no impact because they were not needed [21]

had a negative impact because their contribution was needed [21]

[21]

Were **RESEARCH AND DEVELOPMENT CORPORATIONS / INDUSTRY SERVICE ORGANISATIONS** (for example, Meat & Livestock Australia) either EMPLOYEES OR CONSULTANTS involved in the PROJECT?

yes [22]

no [23]

I am not in a position to know [24]

[22]

When **RESEARCH AND DEVELOPMENT CORPORATIONS / INDUSTRY SERVICE ORGANISATIONS either EMPLOYEES OR CONSULTANTS** were involved

they contributed positively towards the objectives of the PROJECT [24]

they neither contributed positively nor negatively to the objectives of the PROJECT [24]

they made a negative contribution to the PROJECT [24]

[23]

The absence of **RESEARCH AND DEVELOPMENT CORPORATIONS / INDUSTRY SERVICE ORGANISATIONS either EMPLOYEES OR CONSULTANTS** from the PROJECT

had a positive impact because their involvement may have caused problems [24]

had no impact because they were not needed [24]

had a negative impact because their contribution was needed [24]

[24]

Was **GOVERNMENT, in a REGULATOR OR POLICY ROLE** involved in the PROJECT?

yes [25]

no [26]

I am not in a position to know [27]

[25]

When **GOVERNMENT, in a REGULATOR OR POLICY ROLE** were involved

they contributed positively towards the objectives of the PROJECT [27]

they neither contributed positively nor negatively to the objectives of the PROJECT [27]

they made a negative contribution to the PROJECT [27]

[26]

The absence of **GOVERNMENT, in a REGULATOR OR POLICY ROLE** from the PROJECT

had a positive impact because their involvement may have caused problems [27]

had no impact because they were not needed [27]

had a negative impact because their contribution was needed [27]

[27]

Were **SUPPLIERS OF GOODS OR SERVICES** TO THE INDUSTRY involved in the PROJECT?

yes [28]

no [29]

I am not in a position to know [30]

[28]

When **SUPPLIERS OF GOODS OR SERVICES** TO THE INDUSTRY were involved

they contributed positively towards the objectives of the PROJECT [30]

they neither contributed positively nor negatively to the objectives of the PROJECT [30]

they made a negative contribution to the PROJECT [30]

[29]

The absence of **SUPPLIERS OF GOODS OR SERVICES** TO THE INDUSTRY from the PROJECT

had a positive impact because their involvement may have caused problems [30]

had no impact because they were not needed [30]

had a negative impact because their contribution was needed [30]

[30]

Were **CUSTOMERS / CONSUMERS** OF RED MEAT PRODUCTS involved in the PROJECT?

yes [31]

no [32]

I am not in a position to know [33]

[31]

When **CUSTOMERS / CONSUMERS** OF RED MEAT PRODUCTS were involved they contributed positively towards the objectives of the PROJECT [33]

they neither contributed positively nor negatively to the objectives of the PROJECT [33]

they made a negative contribution to the PROJECT [33]

[32]

The absence of **CUSTOMERS / CONSUMERS** OF RED MEAT PRODUCTS from the PROJECT

had a positive impact because their involvement may have caused problems [33]

had no impact because they were not needed [33]

had a negative impact because their contribution was needed [33]

[33]

Were **ENTREPRENEURS / FUNDERS** OF RESEARCH/DEVELOPMENT involved in the PROJECT?

yes [34]

no [35]

I am not in a position to know [36]

[34]

When **ENTREPRENEURS / FUNDERS** OF RESEARCH/DEVELOPMENT were involved

they contributed positively towards the objectives of the PROJECT [36]

they neither contributed positively nor negatively to the objectives of the PROJECT [36]

they made a negative contribution to the PROJECT [36]

[35]

The absence of **ENTREPRENEURS / FUNDERS** OF RESEARCH/DEVELOPMENT from the PROJECT

had a positive impact because their involvement may have caused problems [36]

had no impact because they were not needed [36]

had a negative impact because their contribution was needed [36]

[36]

Were **OTHER GROUPS** involved in the PROJECT?

yes	[37]
no	[39]
I am not in a position to know	[39]

[37]

Who were the **OTHER GROUPS** involved in the PROJECT?

[38]

When **OTHER GROUPS** were involved

they contributed positively towards the objectives of the PROJECT

they neither contributed positively nor negatively to the objectives of the PROJECT

they made a negative contribution to the PROJECT

[39]

Please feel free to comment about the effect that the **INVOLVEMENT OF GROUPS** had on the achievements of the PROJECT

A2.2.5 Structural theory conditions

[7 point scale]

1 – Strongly disagree

2 – Disagree

3 – Somewhat disagree

4 – Neither agree or disagree

5 – Somewhat agree

6 – Agree

7 – Strongly agree

Rules and conventions

[40]

What is your opinion about the following statements regarding **rules and conventions** and the PROJECT?

existing regulations (or absence of regulations) did not constrain the PROJECT

government/regulator general policies (or absence of policies) did not constrain the PROJECT prevailing rules about what was acceptable did not constrain the PROJECT

it was easy to understand what was acceptable

it was easy to understand what was important, or needed to be achieved

there were no difficulties due to industrial/employment practices or issues of industry / regulators

it was easy to fit with the prevailing culture (norms, conventions)

Please feel free to comment on the effect that **rules and conventions** may have had on the achievements of the PROJECT

Interactions

[41]

What is your opinion about the following statements regarding **interactions** and the PROJECT?

the different backgrounds and expertise of those involved contributed to achievement

those involved had common objectives or desires

a common understanding between those involved was gained

trust was developed between those involved

a dominant person/group or a few dominant people/groups contributed to achievement

consensus among one or more groups contributed to achievement

involvement from persons/groups external to the project contributed to achievement

Please feel free to comment on the effect that **interactions** between people or groups may have had on the achievements of the PROJECT

Infrastructure

[42]

What is your opinion about the following statements regarding **infrastructure** and the PROJECT?

communication infrastructure (eg phone, email) was not a constraint

information technology (IT) was not a constraint

transport infrastructure was not a constraint

storage /warehouse infrastructure was not a constraint

power availability was not a constraint

water availability was not a constraint

the availability of equipment or technologies was not a constraint

Please feel free to comment on how **infrastructure** may have affected the achievements of the PROJECT

Market factors

[43]

What is your opinion about the following statements regarding **market factors** and the PROJECT?

The demand by customers for a solution to the problem being addressed in the PROJECT was clear

The size of the market for products/technology produced as a result of this research justifies the PROJECT

The results of this PROJECT are able to be applied easily by a large number of companies

The benefits outweigh the costs of applying the solution proposed by the PROJECT

The effort in applying the results of the PROJECT is small compared to the certain benefits

The PROJECT provided enough information to allow the results to be applied without significant additional expense

Please feel free to comment on the effect **market factors** may have had on the achievements of the PROJECT

A2.2.6 Functional theory conditions

[7 point scale]

1 – Strongly disagree
2 – Disagree
3 – Somewhat disagree
4 – Neither agree or disagree
5 – Somewhat agree
6 – Agree
7 – Strongly agree

Entrepreneurial activities

[44]

During the PROJECT, did the following **entrepreneurial activities** occur?

- researchers discussed ideas with potential users

- potential users were seeking information about what the PROJECT was developing
- there were significant interactions between the researchers and potential users
- suggestions were collected from potential users
- potential users and researchers worked together on the PROJECT
- there was discussion about how the results of the research could be used

Please feel free to comment on the effects **entrepreneurial activities** may have had on the achievements of the PROJECT?

Knowledge development activities

[45]

During the PROJECT, did the following **knowledge development activities** occur?

- knowledge was developed by the research
- the knowledge developed was sufficient for the PROJECT
- the knowledge developed was useful for the PROJECT
- Existing knowledge was refined/defined more precisely through the research
- existing knowledge was applied to a new situation
- the way to apply existing knowledge was defined or refined

Please feel free to comment on the effects **knowledge development** may have had on the achievements of the PROJECT?

Knowledge dissemination

[46]

During the PROJECT, did the following **knowledge dissemination** activities occur?

- new knowledge was published in scientific journals or presented at conferences
- new knowledge was published in a form suitable for the potential users
- new knowledge developed or applied was presented to potential users
- there was consultation between groups or individual researchers and potential users of the new knowledge
- there was a demand by potential users for this research before the work commenced
- interest was being shown by companies, suppliers, regulators or others in this research/technology

- other people or groups were known to be interested in this research/technology

Please feel free to comment on the effects **knowledge dissemination** may have had on the achievements of the PROJECT?

Direction to the PROJECT

[47]

During the PROJECT, did the following activities, that might provide **direction to the PROJECT**, occur?

- Consultation occurred between relevant groups before the work commenced
- Consultation occurred with relevant groups or individuals during the research stage
- Consultation occurred with relevant groups or individuals following the research stage
- Relevant groups were involved in developing a vision for the potential outcomes of the PROJECT
- Regulations or policy development helped to provide direction to the PROJECT
- The requirements or expectations of customers were considered

Please feel free to comment on the effects **direction of the PROJECT** may have had on the achievements of the PROJECT?

Market formation activities

[48]

During the PROJECT, did the following **market formation activities** occur?

- Existing regulation/guidelines/policy helped to develop a clear vision for the PROJECT
- The potential to change or respond to regulation/ guidelines/ policy contributed to clear vision for the PROJECT
- There was a clear demand / need / opportunity for the application of this research/technology
- This PROJECT was expected to meet a need
- This PROJECT was expected to reduce uncertainties in product qualities, process, or regulatory status

Please feel free to comment on the effects **market formation activities** may have had on the achievements of the PROJECT?

Resources

[49]

During the PROJECT, did the following activities relating to **resources** occur?

- The funding available was sufficient
- The necessary expertise was available
- The available expertise was utilised
- Any necessary support (technological infrastructure) was available
- Any products or services needed for the PROJECT were available

Please feel free to comment on the effects **resources** may have had on the achievements of the PROJECT?

Gaining acceptance

[50]

During the PROJECT, did the following activities to **gain acceptance** for the idea occur?

- The idea of the PROJECT was presented to relevant groups
- The idea of the PROJECT was considered by relevant groups
- The idea of the PROJECT was accepted by relevant groups
- Alignment between the idea of the PROJECT and current regulations or policy was considered
- Alignment between the idea of the PROJECT and anticipated or possible changes to regulation or policy was considered

Please feel free to comment on the effects **gaining of acceptance** may have had on the achievements of the PROJECT?

A2.2.7 Qualitative responses

Opinions

[51]

Overall, why do you think this PROJECT did / did not achieve change?

[52]

If the PROJECT did not achieve to its potential, what would have been necessary for the PROJECT to have achieved to its potential?

[53]

You may recall the names of people who were involved in this PROJECT in some way (planning, advising, consulting, implementing). We have been unable to contact everyone we would like. Please provide the name and contact details (preferably email address) of anyone who you think may be able to help by completing this questionnaire.

A2.2.8 Closure

Thank you

Thank you for participating in this survey. Your responses will be valuable in assessing which factors of innovation systems are the most applicable to success in food safety innovation. The results may be relevant to other areas of rural research and development.

Your responses will be submitted to the researchers when you click on the 'done' button below